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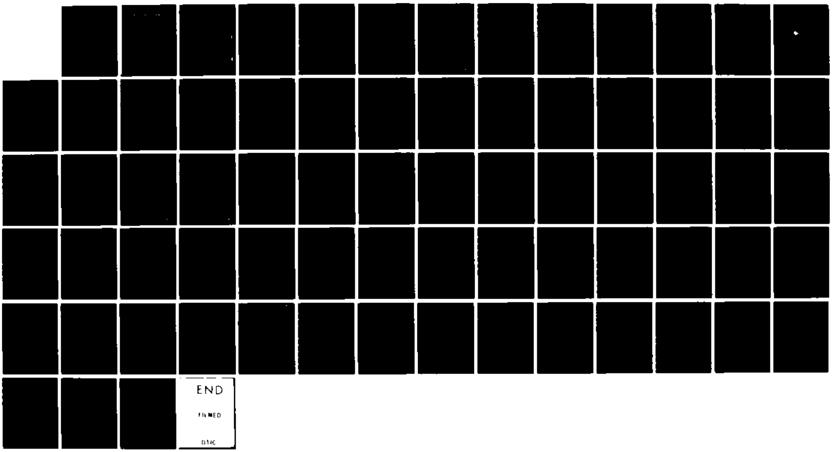

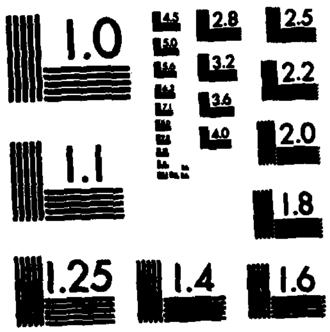

MICROCOPY RESOLUTION TEST CHART

(12)

STANDARDIZATION OF FLAMMABILITY TESTS FOR HYDRAULIC FLUIDS

AD-A146 468

FINAL REPORT
AFLRL No. 181

387356

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U.S. Army Belvoir Research and Development Center
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The modification of the physical and chemical properties of various fluids developed for use as hydraulic fluids has necessitated the development or modification of tests required to evaluate the performance criteria of these fluids. The Federal Government utilized certain Federal Test Method and ASTM flammability test procedures in fluid specification requirements to determine the relative flammability of fluids currently being developed for use as hydraulic fluids. These tests include the flash and fire points,

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autoignition temperatures, flame propagation, high-pressure spray, and hot manifold ignition test procedures. Unfortunately, as fluid composition and applications change, new or modified tests must be developed to provide accurate assessments of the fluids' performance. This report presents the results produced by a systematic study of mist-flammability parameters that will lead to development of a standard mist-flammability test for hydraulic fluid specification purposes.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory located at Southwest Research Institute, San Antonio, Texas, under contract DAAK70-83-C-0070, during the period 5 May 1983 through 30 September 1983. Work was conducted for U.S. Army Belvoir Research and Development Center, Ft. Belvoir, Virginia. Contracting Officer Representative and technical monitor responsibilities were under the Chief, Fuels and Lubricants Division, STRBE-VF, in the Belvoir R&D Center Materials, Fuels and Lubricants Laboratory.

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I. INTRODUCTION

The modification of the physical and chemical properties of various fluids developed for use as hydraulic fluids has necessitated the development or modification of tests required to evaluate the performance criteria of these fluids. The Federal government utilizes certain Federal Test Method and ASTM flammability test procedures in fluid specification requirements to determine the relative flammability of fluids currently being developed for use as hydraulic fluids. These tests include the flash and fire points, autoignition temperatures, flame propagation, high-pressure spray, and hot manifold ignition test procedures. Unfortunately, as fluid composition and applications change, new or modified tests must be developed to provide accurate assessments of the fluids' performance. An excellent example of this point is the "High-Temperature, High-Pressure Spray Ignition, Federal Test Method 791B Method 6052." When this procedure is used to compare the mist ignition and flame propagation characteristics of MIL-H-6083 (petroleum base) and MIL-H-46170 (PAO base), the same results (Table 1) are obtained, thus indicating a lack of discrimination between two fluids of totally different chemical composition.

This report presents the results produced by a systematic study of mist-flammability parameters that will lead to development of a standard mist-flammability test for hydraulic fluid specification purposes.

The mist droplet-size distribution study included evaluations of pressure atomizing-type nozzles of two different manufacturers and determination of their droplet-size distribution patterns and repeatability. The effects on droplet size by variations in atomizing pressure, temperature, and fluid physical properties such as viscosity, density, and surface tension were also determined.

An experimental apparatus was then used to determine dynamic mist ignitability of three MIL-specification fluids of different generic types with the purpose of evaluating the relative importance of different parameters governing the flammability hazards. The independent parametric variations

TABLE 1. RESPONSE OF VARIOUS HYDRAULIC FLUIDS TO HIGH-PRESSURE SPRAY IGNITION (Federal Test Standard 791B--Method 6052)

Fluid	Results
1. MIL-H-5606	Ignition at pilot, self-extinguishing flame
2. MIL-H-6083	Ignition at pilot, self-extinguishing flame
3. MIL-H-83282A	Ignition at pilot, self-extinguishing flame
4. MIL-H-46170	Ignition at pilot, self-extinguishing flame
5. Phosphate Ester	No ignition at 6", 12", or 18"
6. Experimental Silicone A	Ignition at pilot, self-extinguishing flame
7. Experimental Silicone B	Ignition at pilot, self-extinguishing flame

include different types of nozzles, fluid atomizing pressures, fluid temperatures, air temperatures, and air velocities.

II. PROGRAM OBJECTIVES

The overall objective of this program is to develop data and methodology leading to a standardized method(s) for hydraulic fluid flammability assessment.

The work completed toward this end comprised of developing a data-base for mist characteristics and flammability characterization with an oxy-acetylene torch ignition source. Systematic variations in parameters were made to evaluate and identify those of the most critical nature from a flammability viewpoint. The following parameters have been tested for high-pressure spray ignitability:

- Fluid chemical and physical properties
- Fluid system pressure
- Fluid flow rates

- Fluid system temperature
- Air velocity and direction
- Air temperature
- Repeatability of atomizing nozzle

III. EXPERIMENTAL TECHNIQUES

The experimental techniques for testing fluid spray flammability comprised a) characterizing the mist formed by different nozzles and fluids, and b) ignitability of these mists under different environmental conditions.

A. Droplet Size Measurement Apparatus and Instrumentation

The droplet size distribution patterns were determined using a Malvern Model 2200 Droplet and Spray Sizer. The principle of operation of this instrument is based on measurement of the diffraction produced when coherent radiation from a He/Ne laser passes through the spray. A microprocessor-based computer is used to analyze the diffraction pattern produced and to convert that information into a drop size distribution. The total size range covers diameters of 2 to 500 micrometers, although three different focal length lenses are required for the complete range. These data were reduced assuming a Rosin-Rammler two-parameter distribution of spray sizes, although there is also a capability to reduce data assuming a log-normal, or normal distribution. These are all two-parameter models with one parameter indicating an "average" size and the second parameter indicating the width of the size distribution. The width parameter can vary from 0.1 to 1000 where large numbers represent narrower size distributions, with values of 1 to 3 being typical for sprays. In addition to the two-parameter models, a model-independent program can be used which sizes the spray into 15 size classes, independent of any assumptions about the distribution. The raw data have been stored on cassette tapes so that they can be reduced with other models if necessary.

The spray apparatus consists of an electrically heated stainless steel fluid cylinder with heated lines and pressured by compressed nitrogen gas. Tests were run with controlled fluid temperatures. Injection pressure was moni-

tored with a Helicoid gauge (accurate to 5 psi). The fluid spray was contained by spraying into a box 30 cm x 32.5 cm x 90 cm long with windows on each side. A flow of purge air parallel to the nozzle axis was maintained at about 3.2 m/sec for all tests, thus preventing condensation of fluid droplets on the viewing windows as well as recirculation of the spray.

B. Dynamic High-Pressure Mist Spray Flammability Apparatus

High pressure spray flammability was evaluated using a previously developed apparatus shown in Figure 1 with hot manifold ignition source installed instead of oxy-aceylene torch. The apparatus is capable of varying the temperatures and velocities of air surrounding the fluid spray. The fluid reservoir and delivery up to the nozzle is also temperature controlled. Table 2 lists the parameters evaluated for this report.

TABLE 2. HYDRAULIC FLUID HIGH-PRESSURE SPRAY FLAMMABILITY TEST DEVELOPMENT PARAMETERS

1. NOZZLE
   a. TWO MANUFACTURERS: HAGO, DELAVAN
   b. TWO TYPES:
      - 45° SOLID CONE (1.5 GPH NOMINAL)
      - 80° HOLLOW CONE (1.5 GPH NOMINAL)

2. FLUID PARAMETERS:
   a. THREE FLUID TYPES:
      - MIL-H-6083 (PETROLEUM BASE)
      - MIL-H-46170 (POLYALPHAOLEFINS)
      - MIL-L-2104, OE/HDO-10
   b. THREE FLUID TEMPERATURES: 100°F; 150°F; 200°F
   c. THREE FLUID ATOMIZING PRESSURES:
      - 250 PSID; 500 PSID; 1000 PSID

3. AIR PARAMETERS:
   a. THREE VELOCITIES: 0 FPM; 120 FPM; 200 FPM
   b. TWO AIR TEMP: 100°F; 180°F

4. IGNITION: OXY-ACETYLENE TORCH

5. HAZARD CRITERIA
   a. MEASURE TIME:
      - SUSTAINED IGNITION 12+ SEC
      - SELF-EXTINGUISH 0-12 SEC

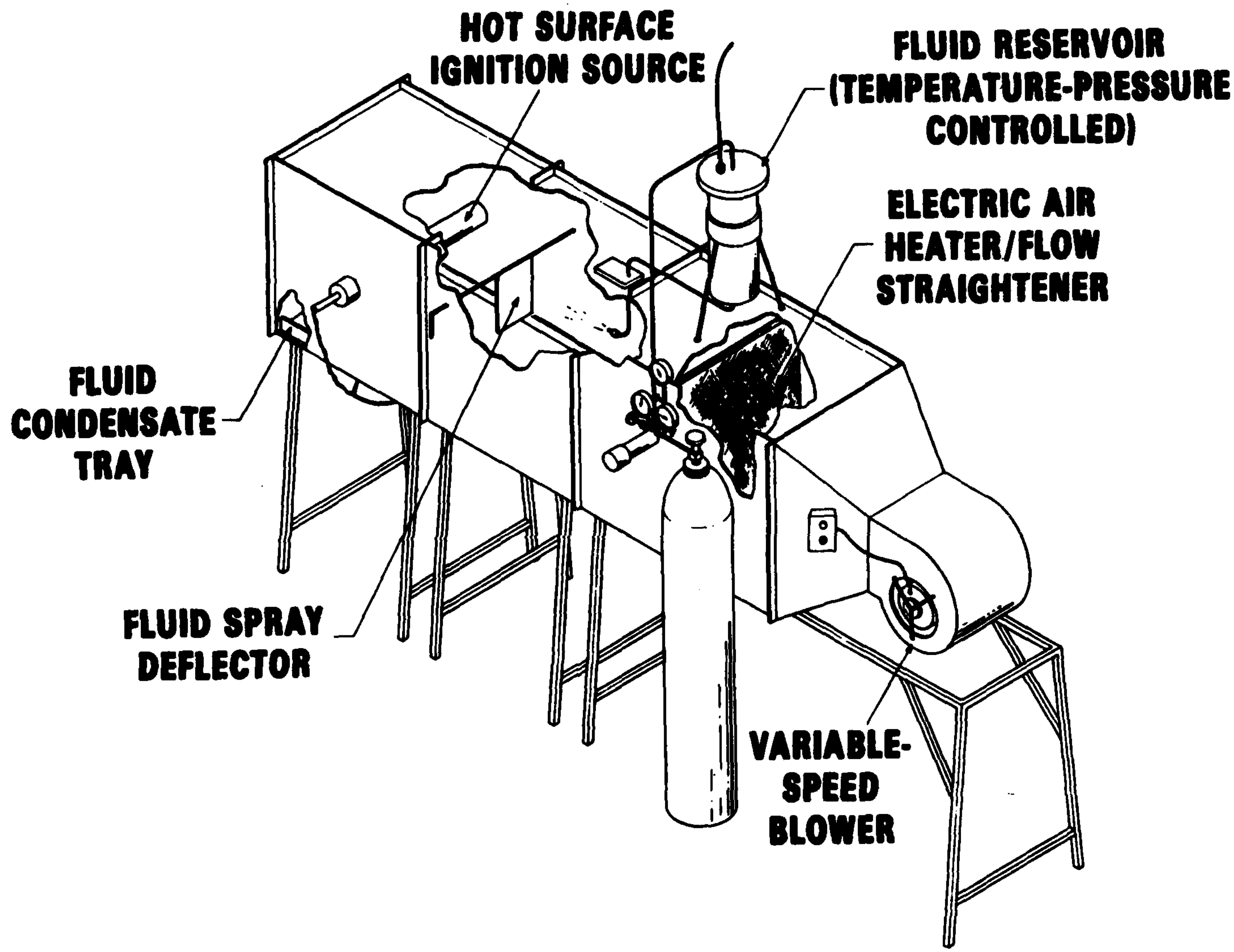

FIGURE 1. DYNAMIC HIGH-PRESSURE MIST SPRAY ANALYZER

IV. RESULTS AND DISCUSSION

A. Mist Characterization

Any mist flammability test must provide a means of generating sprays with drop sizes which are repeatable for a given nozzle, and very similar for different nozzles of the same class. In order to estimate repeatability for nozzles and reproducibility between nozzles of the same type, three nozzle types were tested with samples from two different manufacturers for each type. Six nozzles from each manufacturer were tested for each of the three nozzle classes, for a total of 36 nozzles (Table A1, Appendix A).

Each nozzle was tested at two different fluid pressures, 500 and 1000 psid, at a location on the nozzle axis 6 inches from the nozzle face. Aircraft fuel system calibration fluid type II (MIL-C-7024) was used. Drop size measurements were performed with a Malvern Model 2200 Particle and Droplet Sizer, which is based on the diffraction pattern produced by the drops when illuminated by a He/Ne laser. Air flow parallel to the nozzle spray axis of about 3 m/s was used to prevent recirculation of the spray.

The results that were obtained from the droplet size measurements are presented in Table A1 in Appendix A and summarized as follows:

1) Solid cone nozzles appear to provide an acceptable spray distribution pattern and, in fact, may more closely simulate a pressurized system leak than does the hollow cone nozzle.

2) The currently used nozzle, Hago, appears to give the least repeatable droplet size distribution and indicates additional studies should be conducted to determine if these results are the exception or the normal.

3) A screening process of candidate nozzles (of the same manufacture and class) should precede standardized mist tests to assure that the repeatability between selected nozzles is within specification for use in the standard test.

4) It appears that the narrow cone angle (45°) and lower flow rate nozzles would be acceptable in a standard test and would allow a smaller apparatus than the 80° cone angle nozzles.

The results of nozzle repeatability studies discussed above with calibration fluid Type II (MIL-C-7024) were presented in terms of the Sauter Mean Diameter (SMD) which is an average drop size that is representative of the total droplet surface area-to-volume ratio of the actual drop-size distribution.

In addition to being repeatable, the nozzles should provide as close as is technically feasible the same drop-size distribution at any location within a cross section of the spray perpendicular to the nozzle axis. In order to quantify this, it is necessary to describe a second parameter (in addition to the SMD) which describes how broad a distribution the drop sizes form. The sprays studied here were assumed to follow a Rosin-Rammler distribution where the cumulative volume fraction of drops larger than sized is given by R,

$$R = \exp\,[-(d/\overline{X})^{N})]$$

where $\overline{X}$ represents a size and N a width of the drop size distribution. the SMD in turn is computed from,

$$SMD = X/\,\Gamma(1-1/N) \qquad N > 1$$

where Γ is the Gamma function. It can be seen that large values of N represent narrow distributions and vice versa.

In order to check the uniformity of the spray at a given cross section, several measurements were made for one nozzle from each of the nozzle types at a fixed axial distance of 50 mm from the nozzle face but at various distances radially outward from the nozzle axis. The laser diffraction drop sizer integrates the measured value along the chord where the laser beam intersects the spray. If the drop-size distribution is constant throughout the cross section of the spray 50 mm axially distant from the nozzle, then the measured SMD and N value should be independent of distance from the nozzle axis. Practical swirl nozzles produce sprays which do vary at a given cross section. Drops in the outer cone of the spray tend to be larger

than drops toward the center of the spray. Thus, measurements through the centerline of the spray, which includes both inner and outer cones, should show smaller SMD's and broader size distributions (small N's) than measurements through the outer parts of the spray. This was the case for all nozzles tested (Figures B1 through B4, Appendix B). However, the hollow cone nozzles (Figures B3 and B4) show more variation in spray characteristics as a function of distance from the nozzle axis than the solid cone nozzles (Figures B1 and B2). These tests indicate that the narrower solid cone nozzles produce a more uniform size distribution throughout the cross section of the spray, which is a desirable feature. These nozzles also produce a more uniform number of drops throughout the spray cone than the hollow cone nozzles, also considered a desirable feature. The solid cone Hago nozzle produces a more uniform spray through the cross section than the solid cone Delavan nozzle.

Effect of Fluid Pressure on SMD--Mist flammability depends on a number of factors including drop-size distribution of the hydraulic oil spray. This size distribution depends on fluid properties and fluid pressure. In order to determine the fluid pressure effect on drop size, the four test nozzles were operated with the calibration fluid at pressures of 100, 200, 400, 600, 800, and 1000 psid (689, 1379, 2758, 4137, 5516, and 6895 kPa). Drop-size measurements were made at 6 inches (152 mm) and 12 inches (305 mm) from the nozzle faces. These distances correspond to probable distances between nozzles and ignition sources in the mist flammability test.

The test results for four nozzles at two different distances (as presented in Appendix B Figures B1 to B12) show the spray becomes finer and the distribution broader (N smaller) as the pressure increases. A least squares curve fit to predict SMD as a function of fluid pressure is also shown for each nozzle on Figures B1 to B12. A combination of all four nozzles tested at 6 inches (305 mm) gives SMD Δ $P^{-0.5069}$, and at 12 inches SMD Δ $P^{-0.3776}$.

Spray Drop Sizes as a Function of Fluid Properties and Operating Conditions-In order to establish the effect of fluid properties and operating conditions on sprays of hydraulic fluids used in flammability tests, sprays

from four nozzles have been tested on five hydraulic fluids of widely varying properties, at three different nozzle pressures and two different distances from the nozzles. Spray drop sizes were measured using a Malvern Model 2200 Drop Sizer which utilizes the forward diffraction pattern from a laser beam. The four hydraulic fluids and their properties are shown in Table A2, with a range of viscosities form 4.0 to 90 sC (at 25°C). Pressure drop across the nozzles was set at 250 psi (1724 kPa), 500 psi (3447 kPa), and 1000 psi (6895 kPa). Drop sizes were measured at 6 inches (15.2 cm) and 12 inches (30.5 cm) from the nozzle tip. Four nozzles were tested, consisting of two nozzle types - nominal 1.0 gallon per hour (3.8 liter/hr) 45° solid cone, and nominal 1.5 gallon per hour (5.7 liter/hr) 80° hollow cone, with each nozzle type being duplicated by two manufacturers - Hago and Delavan. The spray drop sizes were correlated by their Sauter Mean Diameters (SMD) using an equation of the form,

$$SMD = a\ (\Delta P)^b\ Z^c\ \gamma^d\ (SpGr)^e$$

or

$$SMD = f\ (w)^g\ Z^c\ \gamma^d\ (SpGr)^e$$

where a and f are constants, ΔP is the pressure in psig, Z is the distance in inches, γ is the absolute viscosity in centistokes, SpGr is the specific gravity, and w is the mass flow in grams/minute. The constants and coefficients for these equations for the four nozzles have been determined. The flow rate w is highly correlated with the pressure drop ΔP so that the SMD may be correlated with either one but not both in the same equation.

B. Mist Ignitability Under Dynamic Conditions

The mist ignitablity of three hydraulic fluids MIL-H-6083, MIL-H-46170 and MIL-L-2104 was evaluated with the test apparatus and conditions described in Table 2. The ignition source was an oxy-acetylene torch with a 3-inch blue flame. If self-extinguishment of the mist fire occured after the removal of the ignition source, the time was recorded. However, if the fire continued longer than 12 seconds the test was terminated with the rating of sustained ignition. The detailed data are presented in Tables A4 through A15.

An overall examination of the burn time data suggests that the test conditions can discriminate between the three fluids used such that MIL-L-2104 self-extinguishes more often and in shorter times than MIL-H-46170; and, similarly, MIL-H-6083 is more flammable than MIL-H-46170.

V. ANALYSIS OF THE FLAMMABILITY DATA

The flammability tests cover 648 test conditions derived from a complete matrix of 3 fluids, 4 nozzles, 3 fuel-pressure drops, 3 air velocities, 2 air temperatures, and 3 fluid temperatures. At each of the 648 test conditions, the tests were performed 3 times, so the total number of data sets is 1944. Of these, 270 cases were excluded because the atomization was so poor with some of the viscous fluids at room temperature with low atomizing pressures that the SMD could not be determined reliably. For each of the remaining 1674 tests, the dependent variable is the length of time the flame burns before extinguishing. In some cases, the flame continues to burn indefinitely, while in other cases it may eventually extinguish, but burn time period must be limited to conserve fluid and prevent damage and safety problems. Additionally, if the flame burns beyond some set time, it can be argued that a real fire would have caused serious damage by that time, even if it extinguishes at a later time. Thus, the time to flame extinguishment was measured up to 12 seconds, and that time was reported, or the fact that it survived at least 12 seconds was reported. Out of all the tests, 60.3 percent of the flames survived the full 12 seconds.

What type of analysis can be applied to these data? Is it desirable to predict the actual burn time ignoring the 60.3 percent of the data which burned beyond the end of the test, or to predict what conditions lead to "serious" fires lasting at least 12 seconds, and which ones lead to fires which extinguish before that time? Also, is it more important to use as independent variables the experimental conditions which were varied (atomizer pressure, fluid temperature, air velocity, air temperature, and fluid volatility) as an experimentalist might prefer, or to use more fundamental properties such as Sauter mean diameter (SMD) of the spray drops, the mass

transfer number B (which depends on the fluid boiling point and initial temperature) the mass flow rate, and the air velocity as a theoretician would prefer? The answer, of course, is all of the above, depending on what the data is being used for. In designing a standardized flammability test, it is necessary to evaluate the sensitivity of the results to the experimental variables. On the other hand, to understand and predict results which can be extrapolated to other hydraulic fluids, it is necessary to investigate the effects on flammability of the variation of the more fundamental properties. For these reasons, the data were analyzed several ways to broaden their usefulness.

First, from the standpoint of designing a standardized mist flammability test, it is important to determine which of the experimental variables contribute strongly to the observed results. Of the four nozzles tested and shown in Table 3, there are definite differences in flammability between the nozzle types, and slight differences between manufacturers (or nozzle to nozzle variations) for the 45° cone angle case. The wider cone angle of the 80° cone angle nozzles probably contribute to the greater flammability observed. The Delavan 45° nozzle produced smaller drops than the Hago 45°, generally, and showed a correspondingly higher flammability rating. Thus, for a standardized test, nozzles must be of the same type and should be tested and selected to produce SMD's within approximately 10 percent of a control value.

TABLE 3. EFFECT OF NOZZLE TYPE ON FLAMMABILITY RESULTS

Nozzle Mfg.	Cone Angle (Degrees)	Nominal Flow Rate @ 100 psid gal/hr	Fraction of Tests Burning >12 sec.
Hago	45	1.5	0.5124
Delavan	45	1.5	0.5658
Hago	80	1.5	0.6749
Delavan	80	1.5	0.6584

There are, of course, large differences in the flammabilities of the different fluids, as shown in Table 4. To determine how sensitive these results

TABLE 4. FLAMMABILITIES OF DIFFERENT HYDRAULIC FLUIDS

Fluid	Fraction of Tests Burning >12 sec
MIL-L-2104	0.3472
MIL-H-46170	0.5849
MIL-H-6083	0.8766

were to the experimental variables, an analysis of variance was conducted considering the results from all the tests for fluid MIL-L-2104. This fluid was chosen because it had the most data for discrete burn times where tests did not exceed 12 seconds, although for this analysis the burn time was divided into two groups of less than or greater than 12 seconds of burning. The results of the analysis of variance, shown in Table 5, indicate the air velocity was the most critical experimental variable, but also of high significance were fluid temperature, nozzle pressure drop and nozzle type. This analysis and others showed that air temperature was relatively insignificant over the range tested (100°F - 180°F). The F ratio in Table 5 gives a measure of whether or not a variable is significant in determining the flammability, with values in excess of 2 of 3 considered significant. The "tail prob." in Table 5 gives the probability that a variable is not significant in predicting flammability.

Another way of evaluating the relative sensitivity of different experimental parameters is to attempt to predict the burn times (T_b) from a correlation equation of the form

$$T_b = K\ (\Delta P)^a (T_F)^b\ (T_A)^c (250-V_a)^d \qquad (1)$$

where K is a constant, and a, b, c, and d are exponents, all of which are determined from a multiple linear regression analysis. The value $(250-V_a)$ is used in place of V_a because, in order to get a correlation of the form shown in Eq. 1, logarithms must be taken of all the variables and V_a ranges from 0 to 200 ft/min. The burn times in excess of 12 seconds may either be

TABLE 5. ANALYSIS OF VARIANCE, DEPENDENCE, ON EXPERIMENTAL PARAMETERS, FLAMMABILITY OF MIL-L-2104

Parameter	F Ratio	Tail Prob.
V_{AIR}	812.4	0.0000
T_F	77.4	0.0000
ΔP	37.7	0.0000
Nozzle	15.9	0.0000
T_A	0.3	0.6118

ignored or treated as flames that extinguished at 12 seconds. The second choice results in a better correlation, with the results as presented in Table 6, considering data for fluid MIL-L-2104. For the components given in Table 6, the units of ΔP are psid (differential), T_F and T_A in degrees

TABLE 6. REGRESSION OF EXPERIMENTAL PARAMETERS FOR FLAMMABILITY OF MIL-L-2104

Variable	Exponent	Std. Reg. Coeff.	T	P(2 Tail)
K	exp(-25.620)			
ΔP	0.187	0.078	2.610	0.0094
T_F	3.70	0.301	10.023	0.0000
T_A	0.032	0.003	0.085	0.9321
$(250-V_a)$	0.897	0.719	23.905	0.0000

Overall correlation coefficient R = .784

$$T_b = K\ \Delta P^a T_F{}^b T_A{}^c (250-V_a)^d$$

Kelvin, and V_a in feet per minute. Again this fluid was chosen because it had the least number of burns in excess of 12 seconds (35 percent). Along with the exponents listed in Table 6 are the standardized regression coefficients, which indicate the relative importance of variations in the different experimental variables, the T ratio which is the exponent divided by

the estimated standard error in the exponent, and P (2 Tail) which is the probability that the variable is not significant to the correlation. The relative importance of the experimental variables, as indicated by the standardized regression coefficients is in the same order as determined by the analysis of variance, except that nozzles are not included in this analysis. The air velocity and fluid temperature are critical, the nozzle pressure-drop mildly significant, and the air temperature insignificant. Also significant differences were seen between the nozzles. What is referred to as air velocity is actually air mass flow rate measured as a velocity at a standard condition. Increasing air temperature both increases the air velocity, decreasing flammability and increases spray evaporation, increasing flammability. The net results apparently cancel for changes in air temperature.

In order to gain a better understanding of hydraulic fluid flammability and make these results more generally applicable, it is necessary to consider what physical phenomena lead to flame extinction, and what variables are important to these phenomena. One effect leading to extinction is blowoff. That is, the air flow carries the flame away from the nozzle faster than it can propagate upstream. However, a second mechanism is also contributing to extinction even at zero air velocity. This is evidently due to the heat loss rate being greater than the heat generation rate within the flame volume. Since heat generation rates are proportional to the volume of burning sphere and heat losses to the area, this type of flame propagation or extinction is analyzed in terms of a minimum quenching diameter which must be exceeded for the flame to propagate. Thus, flame extinction may occur if the air velocity exceeds the propagation velocity or if the flame diameter is smaller than the quenching diameter,

$$\text{Extinction} \quad \left\{ \begin{array}{l} V_a > V_{\text{flame speed}} \\ \\ d_{\text{flame}} < d_{\text{quench}} \end{array} \right.$$

and these effects are actually coupled rather than completely separable.

Flame speeds for laminar flowing gaseous mixtures are typically about 50 cm/sec. Turbulence tends to increase the burning rate due to any or all of the following: (1) turbulence increases the surface area of the flame; (2) turbulence increases heat and mass transport increasing the flame speed; and/or (3) high levels of turbulence rapidly mix the burned and unburned gases so that that flame approaches a more homogeneous mixture. At the 120 ft/min (61 cm/sec) velocity, the Reynolds number for the test chamber is about 18,000, while at 200 ft/min (102 cm/sec) the Reynolds number is about 30,000. Thus, flow in the test chamber is turbulent and the flame speed is enhanced such that the flame is able to sustain itself for some conditions at air velocities of 102 cm/sec, well in excess of the laminar flame speed of 50 cm/sec. Although flame speed is enhanced by turbulence, it is reduced by the presence of fuel droplets which require time to vaporize before they can be burned.

An estimate of the drop evaporation time to produce sufficient fluid vapor to support combustion is given by Peters and Mellor.(1-2)*

$$\tau_e \sim (D^2/\phi \ln (1+B))(\rho_f c_{pa}/8k_a) \qquad (2)$$

where D is the SMD, ϕ is the stoichiometry, B is the transfer number, ρ_f is the fluid density, c_{pa} is the specific heat at constant pressure for air, and k_a is the thermal conductivity of air. The terms in the second group on the right side of Eq. 2 are approximately constant for these experiments, while the terms in the first group vary for different tests. Thus τ_e, and hence, flame speed, is sensitive to changes in D, ϕ, and B. Flame speed is also sensitive to turbulence intensity V_a' which is assumed to vary with air velocity V_a. A correlation involving extinction due to blowoff should involve the parameters V_a, D, ϕ, and B.

Equations for quenching distance, d_q, for ignition are given by Ballal and Lefebvre (3)

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*Underscored numbers in parentheses refer to the references at the end of this report.

$$d_q = 1 + \left[\frac{0.8\ V_a{}'d_q}{\alpha}\right]^{0.5} \left[\frac{(1-\Omega)\rho_f D^2}{\rho_a \phi \log(1+B)(1+0.25\ Re_D^{0.5})} + \left(\frac{10\,\alpha}{S_L - 0.16 V_a{}'}\right)^2\right]^{0.5}$$

where the new terms are Ω, the fraction of total fluid in the vapor form, α, the thermal diffusivity of air, and S_L, the laminar flame speed. Ignoring the terms which are approximately constant, the variables of importance are $V_a{}'$, Ω, D, ϕ, B, and Re_D. The evaporated fuel fraction Ω depends mostly on B and D, while Re_D, the Reynolds number relative to the drop size, varies with D. Thus to correlate extinction based on minimum quenching size, the variables of importance are V_a, D, ϕ, and B, the same set arrived at before for quenching by blowoff.

The set of "fundamental" (as opposed to experimental) variables is seen to be V_a, D, ϕ, and B. The air velocity V_a is determined directly. The drop size D was measured previously as a function of atomizer pressure drop, distance from the nozzle, and fluid. All SMD measurements were conducted at room temperature but correlations were developed to relate SMD to pressure drop, mass flow rate, viscosity, and specific gravity. Using these correlations, the SMD's measured at 6 inches (15 cm) from the nozzle were corrected for the reduced viscosity due to the elevated fluid temperature used in the flame extinction experiments. Since the nozzle fluid feed lines were insulated, the air temperature was assumed to have no effect on the fluid temperature. The stoichiometry ϕ was assumed to be proportional to the volume flow rate $\dot{Q}$. The transfer number B depends on the fuel volatility and fluid temperature according to the relationship (Spalding, 1955),

$$B = \frac{q_{st}\,H + c_{p,a}\,(T_g - T_b)}{L + c_{p,f}\,(T_b - T_f)} \qquad (4)$$

where q_{st} is the fluid air ratio by mass at stoichiometric fluid air ratio, H is the heat of combustion, $c_{p,a}$ and $c_{p,f}$ are the specific heats at constant pressure for the air and fluid, T_g is the gas temperature of the flame, taken as 2000 K, T_b is the boiling point of the fuel, L is the latent heat of vaporization, and T_f is the initial fluid temperature. The necessary fluid properties are presented in Table 7.

TABLE 7. HYDRAULIC FLUID PROPERTIES

Fluid	50% Dist. Temp. K	L (kJ/kg)	H (kJ/kg)	$C_{p,fo}$ (kJ/kg.°K)
MIL-H-6083	537	247	42133	1.97
MIL-H-46170	705	205	41202	2.10
MIL-L-2104	714	154	35383	2.10

These fundamental variables V_a, D, $\dot{Q}$ (proportional to ϕ), and B were correlated in various ways with the observed burn times. They were correlated with the observed burn times excluding all tests where burn time exceeded the 12 second test duration, and they were also correlated in the same way but including the tests with burn times in excess of 12 seconds, but assuming those flames extinguished at 12 seconds. The results of these two correlations were similar but the correlation coefficient for the second case was greater. The correlation was assumed to have the form,

$$T_b = K\ (250-V_a)^a D^b \dot{Q}^c B^d \tag{5}$$

where K is a constant and a, b, c, and d are exponents determined from the regression analysis. The results are given in Table 8 and indicate that V_a, D, and B are definitedly significant parameters, but $\dot{Q}$ is not significant as indicated by the large value of P(2 tail) which measured the probability that a variable has a zero coefficient, i.e., is insignificant. The standardized regression coefficient indicates that the correlation is most sensitive to V_a, but both B and D are also necessary. The exponnents on $(250-V_a)$, B, and D are the sign expected. Increasing V_a decreases T_b, increasing D decreases T_b, and increasing B (volatility) increases T_b.

Perhaps the most suitable way of analyzing the data from a fundamental standpoint is to predict the flammability envelope. That is, if the air velocity (V_a) and drop size (D) are small, the flow rate ($\dot{Q}$) and volatility (B) are high, there is a high probability that the flame will burn for more than 12 seconds. On the other hand, for large V_a and D, and small $\dot{Q}$ and B,

TABLE 8. REGRESSION OF FUNDAMENTAL VARIABLES FOR FLAMMABILITY OF ALL FLUIDS

Variable	Exponent	Coeff.	T	P(2 Tail)
K	exp(-1.191)			
V	.5956	.581	35.56	.0000
D[a]	-.2837	-.191	-9.13	.0000
Q	-.0099	-.005	-0.23	.8194
B	.8074	.347	19.60	.0000

Overall correlation coefficient R = .735

$T_b = K\ V_a^a D^b \dot{Q}^c B^d$

the flame will probably extinguish before 12 seconds. Of course, any time may be picked in place of 12 seconds but that was the time chosen for this experiment. The problem remains to define mathematically the envelope in four-dimensional space which includes the dependencies of V_a, D, $\dot{Q}$, and B and separates, with a high proability of success, the regions where these variables have values which will lead to sustained burning from those regions where the flame will self-extinguish. There are various approaches to this problem, but one which has shown success is the following.

Air velocity was the most sensitive parameter for causing transitions from flammable cases ($\geq$ 12 seconds of burn) to self-extinguishing cases (< 12 seconds), as shown in the previous analyses. Increasing air velocity lead to self-extinguishing flames in 77 of 93 sets of data. These sets were composed of all tests conducted at constant D, $\dot{Q}$, and B which included a matrix of 3 different air velocities, 2 air temperatures, and 3 repetitions for a total of 18 tests in each set. For the 77 sets where transitions to self-extinguishing flames occured, the blowoff air velocity was determined as a function of D, $\dot{Q}$, and B using an equation of the form,

$$V_{a,b} = 250 - K\ D^a \dot{Q}^b B^c \quad (7)$$

with the results as shown in Table 9.

TABLE 9. REGRESSION ANALYSIS OF TRANSITION AIR VELOCITY WITH DROP SIZE, FLUID FLOW RATE, AND TRANSFER NUMBER

Variable	Exponent	T
K	exp(8.597)	
D	.1486	1.89
$\dot{Q}$	-.4517	-4.43
B	-1.2130	-8.98

$(250-V_{a,b})=K\ D^{a}\dot{Q}^{b}B^{c}$

or

$V_{a,b}=250-K\ D^{a}\dot{Q}^{b}B^{c}$

This equation may be interpreted as follows.

Consider the variations of the blowoff velocity $V_{a,b}$ with volatility which is contained in the transfer number B. Assume that D and $\dot{Q}$ are fixed at typical values of D = 40 micrometer and $\dot{Q}$ = 200 ml/min then Eq. 7 becomes,

$$V_{a,b} = 250 - 772\ B^{-1.213} \tag{8}$$

As B becomes very large simulating a high volatility fluid, the predicted blowoff velocity approaches 250 ft/min (127 cm/sec). This is selected to be the turbulent flame speed for a completely vaporized mixture for these experimental conditions. Actual B values for these fluids ranged from about 3.8 to 8.4, resulting in predicted blowoff velocities from 97 to 192 ft/min (49 to 98 cm/sec) for D = 40 micrometers and $\dot{Q}$ = 200 ml/min.

For each of the 1674 tests the values of D, $\dot{Q}$, and B were substituted into Eq. 7 and a blowoff velocity predicted. If the actual air velocity was less than the predicted blowoff velocity, a sustained flame was predicted. Conversely, if the actual air velocity was greater than the predicted blowoff velocity, a self-extinguishing flame was predicted. Of the 1674 tests, 1441, or 86.1 percent were correctly predicted to be sustained or self-extinguishing by this criteria.

VI. CONCLUSIONS AND RECOMMENDATIONS

On the basis of regression analysis performed on the experimental parameters, the air velocity appears to be the most critical to get reproducible results from tests at different laboratories. The temperature of the fluid is also critical, but should be more easily measured than the air velocity and air velocity distribution. The nozzle pressure is important but should be relatively easy to control. The nozzles must be standardized both in terms of type and manufacturer and should be tested and preselected to maintain uniformity between laboratories. The air temperature is unimportant for this type of experiment over the expected range of variation and requires only minimal control.

From a fundamental standpoint the flammability of these fluids is controlled by four parameters, the air velocity, the transfer number (B) which is a measure of the volatility, the drop size distribution, and the fluid flow rate. If these parameters are known the flammability of the fluid may be predicted for this type of experiment.

It is recommended that:

- the controlling test parameters identified above be used to develop a standardized procedure and to allow a formulation of precision statement.
- It is also recommended that a more broad matrix of test fluids be evaluated, including water based fluids.

VII. REFERENCES

1. Peters, J. E., and Mellor, A. M., "An Ignition Model for Quiescent Fuel Sprays," Combustion and Flame, 38, 65, 1980.

2. Peters, J. E., and Mellor, A. M., "Characteristic Time Ignition Model Extended to an Annular Gas Turbine Combustor," presented at the Western States Section/the Combustion Institute, WSCI 81-39, 1981.

3. Ballal, D. R., and Lefebvre, A. H., "A General Mode of Spark Ignition for Gaseous and Liquid Fuel-Air Mixtures," Proceedings of the 18th Symposium (International) on Combustion, the Combustion Institute, p. 1737, 1980.

APPENDIX A

TABLES OF EXPERIMENTAL DATA

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TABLE A-1 NOZZLE REPEATABILITY TESTS*

	SMD Avg. 3 Tests (μm)	SMD Std. Deviation (μm)	SMD Avg. of Nozzles (μm)	SMD Std. Deviation (μm)
Hago 1.0 gph, 45°C ES (Solid Cone)				
500 psid				
Nozzle No.				
1	24.9	0.4	—	—
2	22.1	0.7	—	—
3	19.8	1.0	—	—
4	20.4	0.3	—	—
5	21.4	0.0	—	—
6	20.4	0.3	—	—
			21.5	1.7
1000 psid				
Nozzle No.				
1	18.0	0.5	—	—
2	14.0	0.4	—	—
3	13.9	0.8	—	—
4	13.7	0.4	—	—
5	16.0	0.4	—	—
6	13.7	0.2	—	—
			14.9	1.6
Delavan 1.0 (gph), 45°B (Solid Cone)				
500 psid				
Nozzle No.				
1	22.2	0.1	—	—
2	20.5	0.3	—	—
3	19.2	0.2	—	—
4	21.7	0.1	—	—
5	20.0	0.0	—	—
6	21.8	0.1	—	—
			20.9	1.1
1000 psid				
Nozzle No.				
1	16.9	0.4	—	—
2	14.6	0.4	—	—
3	12.4	0.2	—	—
4	15.6	0.1	—	—
5	12.4	0.2	—	—
6	15.8	0.3	—	—
			14.6	1.7

*All tests were conducted on the centerline of the nozzle 6 inches from the nozzle face using aircraft fuel system calibration fluid Type II (MIL-C-7024).

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TABLE A-1 NOZZLE REPEATABILITY TESTS*
(Cont'd)

	SMD		SMD	
	Avg. 3 Tests (μm)	Std. Deviation (μm)	Avg. of Nozzles (μm)	Std. Deviation (μm)
Hago 1.5 gph, 45°C ES (Solid Cone)				
500 psid				
Nozzle No.				
1	17.4	0.0	—	—
2	22.3	0.2	—	—
3	20.1	0.1	—	—
4	19.8	0.5	—	—
5	20.2	0.5	—	—
6	18.1	0.2	—	—
			19.7	1.6
1000 psid				
Nozzle No.				
1	12.5	0.2	—	—
2	13.9	1.1	—	—
3	14.0	0.2	—	—
4	12.2	0.1	—	—
5	13.7	0.6	—	—
6	15.6	0.0	—	—
			13.7	1.1
Delavan 1.5 (gph), 45°B (Solid Cone)				
500 psid				
Nozzle No.				
1	24.0	0.6	—	—
2	24.3	0.2	—	—
3	24.5	0.3	—	—
4	23.3	0.9	—	—
5	19.6	0.4	—	—
6	23.8	0.4	—	—
			23.3	1.7
1000 psid				
Nozzle No.				
1	17.0	0.2	—	—
2	19.0	0.1	—	—
3	19.2	0.7	—	—
4	15.8	0.6	—	—
5	10.7	0.0	—	—
6	17.5	0.3	—	—
			16.5	2.9

TABLE A-1 NOZZLE REPEATABILITY TESTS*
(Cont'd)

	SMD Avg. 3 Tests (µm)	SMD Std. Deviation (µm)	SMD Avg. of Nozzles (µm)	SMD Std. Deviation (µm)
Hago 1.5 gph, 80°C H (Hollow Cone)				
500 psid				
Nozzle No.				
1	19.4	0.4	—	—
2	15.3	0.4	—	—
3	21.5	0.4	—	—
4	24.5	1.1	—	—
5	21.3	0.2	—	—
6	16.6	1.0	—	—
			19.8	3.1
1000 psid				
Nozzle No.				
1	10.7	0.2	—	—
2	7.7	0.1	—	—
3	16.0	0.9	—	—
4	18.8	0.4	—	—
5	14.4	0.3	—	—
6	10.4	0.4	—	—
			13.0	3.8
Delavan 1.5 (gph), 80°B (Hollow Cone)				
500 psid				
Nozzle No.				
1	18.7	0.3	—	—
2	19.4	0.4	—	—
3	17.9	0.2	—	—
4	18.8	0.3	—	—
5	21.8	0.3	—	—
6	17.5	0.2	—	—
			19.0	1.4
1000 psid				
Nozzle No.				
1	13.8	0.2	—	—
2	14.7	0.0	—	—
3	13.5	0.2	—	—
4	13.9	0.4	—	—
5	15.6	0.0	—	—
6	14.0	0.4	—	—
			14.3	.7

TABLE A-2 FLUID PROPERTIES

Fluid	Viscosity, cS at 76°F	Sp.Gr.	Surface Tens. dynes/cm	50% Dist. Temp. °K
MIL-H-6083	21.30	.8602	28.99	537
MIL-H-46170	27.37	.8618	30.97	705
MIL-L-2104C OE/HDO-10	89.67	.8833	32.71	714
Halocarbon	4.0	1.87	27.83	476

TABLE A-3 EXPONENTS AND CONSTANTS FOR CORRELATION OF NOZZLE SMD WITH FUEL PROPERTIES AND OPERATING CONDITIONS

Nozzle Mfg.	Nozzle: Nominal Flow Rate (gph)	Nozzle: Nominal Cone Angle	Exponents & Constants for Correlation Equation: a const.	b (ΔP)	c (Z)	d (ν)	e (SpGr)	f const.	g (w)
Hago	1.0	45° (Solid)	97.1	-.462	.299	.502	.107	--	--
			--	--	.299	.482	.309	467.5	-.865
Delavan	1.0	45° (Solid)	78.3	-.487	.332	.577	.248	--	--
			--	--	.332	.604	.460	457.0	-.954
Hago	1.5	80° (Hollow)	74.4	-.420	.331	.459	--	--	--
			--	--	.331	.501	.327	344.1	-.783
Delavan	1.5	80° (Hollow)	131.2	-.484	.360	.393	--	--	--
			--	--	.360	.485	.488	1315	-1.021

(SPEC02.A)

TABLE A-4 MIL-H-6083 HIGH-PRESSURE SPRAY FLAMMABILITY
WITH OXY-ACETYLENE TORCH AND HAGO 45° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish* Event No. 1	Event No. 2	Event No. 3
250	100	0	100	---*	---	---
250	100	120	100	---	---	---
250	100	200	100	2	3	2
250	100	0	180	---	---	---
250	100	120	180	---	---	---
250	100	200	180	5	3	8
250	150	0	100	---	---	---
250	150	120	100	6	6	---
250	150	200	100	3	4	3
250	150	0	180	---	---	---
250	150	120	180	---	---	---
250	150	200	180	3	3	5
250	200	0	100	---	---	---
250	200	120	100	---	---	---
250	200	200	100	8	4	12
250	200	0	180	---	---	---
250	200	120	180	---	---	---
250	200	200	180	2	2	3
500	100	0	100	---	---	---
500	100	120	100	---	---	---
500	100	200	100	4	4	5
500	100	0	180	---	---	---
500	100	120	180	---	---	---
500	100	200	180	11	---	8
500	150	0	100	---	---	---
500	150	120	100	---	---	---
500	150	200	100	---	---	---
500	150	0	180	---	---	---
500	150	120	180	---	---	---
500	150	200	180	7	---	---
500	200	0	100	---	---	---
500	200	120	100	---	---	---
500	200	200	100	---	---	---
500	200	0	180	---	---	---
500	200	120	180	---	---	---
500	200	200	180	5	8	4

(Continued)

* --- Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-4 MIL-H-6083 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND HAGO 45° NOZZLE (Continued)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish*		
				Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	---*	---	---
1000	100	120	100	---	---	---
1000	100	200	100	4	3	6
1000	100	0	180	---	---	---
1000	100	120	180	---	---	---
1000	100	200	180	---	---	---
1000	150	0	100	---	---	---
1000	150	120	100	---	---	---
1000	150	200	100	---	---	---
1000	150	0	180	---	---	---
1000	150	120	180	---	---	---
1000	150	200	180	---	---	---
1000	200	0	100	---	---	---
1000	200	120	100	---	---	---
1000	200	200	100	---	---	---
1000	200	0	180	---	---	---
1000	200	120	180	---	---	---
1000	200	200	180	2	2	3

* --- Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-5 MIL-H-6083 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND DELAVAN 45° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish*		
				Event No. 1	Event No. 2	Event No. 3
250	100	0	100	---*	---	---
250	100	120	100	---	---	---
250	100	200	100	3	3	4
250	100	0	180	---	---	---
250	100	120	180	---	---	---
250	100	200	180	3	3	4
250	150	0	100	---	---	---
250	150	120	100	---	---	---
250	150	200	100	4	5	5
250	150	0	180	---	---	---
250	150	120	180	---	---	---
250	150	200	180	5	12	---
250	200	0	100	---	---	---
250	200	120	100	---	---	---
250	200	200	100	6	6	6
250	200	0	180	---	---	---
250	200	120	180	---	---	---
250	200	200	180	5	3	4
500	100	0	100	---	---	---
500	100	120	100	---	---	---
500	100	200	100	7	10	---
500	100	0	180	---	---	---
500	100	120	180	---	---	---
500	100	200	180	---	---	---
500	150	0	100	---	---	---
500	150	120	100	---	---	---
500	150	200	100	5	12	---
500	150	0	180	---	---	---
500	150	120	180	---	---	---
500	150	200	180	---	---	---
500	200	0	100	---	---	---
500	200	120	100	---	---	---
500	200	200	100	---	---	---
500	200	0	180	---	---	---
500	200	120	180	---	---	---
500	200	200	180	3	---	---

(Continued)

* --- Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-5 MIL-H-6083 HIGH-PRESSURE SPRAY FLAMMABILITY
WITH OXY-ACETYLENE TORCH AND DELAVAN 45° NOZZLE
(Continued)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish* Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	---	---	---
1000	100	120	100	---	---	---
1000	100	200	100	---	---	---
1000	100	0	180	---	---	---
1000	100	120	180	---	---	---
1000	100	200	180	---	---	---
1000	150	0	100	---	---	---
1000	150	120	100	---	---	---
1000	150	200	100	---	---	---
1000	150	0	180	---	---	---
1000	150	120	180	---	---	---
1000	150	200	180	---	---	---
1000	200	0	100	---	---	---
1000	200	120	100	---	---	---
1000	200	200	100	---	---	---
1000	200	0	180	---	---	---
1000	200	120	180	---	---	---
1000	200	200	180	---	---	---

* --- Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-6 MIL-H-6083 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND HAGO 80° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish* Event No. 1	Event No. 2	Event No. 3
250	100	0	100	---*	---	---
250	100	120	100	---	---	---
250	100	200	100	8	5	6
250	100	0	180	---	---	---
250	100	120	180	---	---	---
250	100	200	180	6	4	4
250	150	0	100	---	---	---
250	150	120	100	---	---	---
250	150	200	100	---	---	---
250	150	0	180	---	---	---
250	150	120	180	---	---	---
250	150	200	180	4	8	---
250	200	0	100	---	---	---
250	200	120	100	---	---	---
250	200	200	100	---	---	3
250	200	0	180	---	---	---
250	200	120	180	---	---	---
250	200	200	180	4	3	---
500	100	0	100	---	---	---
500	100	120	100	---	---	---
500	100	200	100	---	---	---
500	100	0	180	---	---	---
500	100	120	180	---	---	---
500	100	200	180	---	---	---
500	150	0	100	---	---	---
500	150	120	100	---	---	---
500	150	200	100	---	---	---
500	150	0	180	---	---	---
500	150	120	180	---	---	---
500	150	200	180	---	---	---
500	200	0	100	---	---	---
500	200	120	100	---	---	---
500	200	200	100	---	---	---
500	200	0	180	---	---	---
500	200	120	180	---	---	---
500	200	200	180	---	---	---

(Continued)

* --- Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-6 MIL-H-6083 HIGH-PRESSURE SPRAY FLAMMABILITY
WITH OXY-ACETYLENE TORCH AND HAGO 80° NOZZLE
(Continued)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish* Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	---*	---	---
1000	100	120	100	---	---	---
1000	100	200	100	---	---	---
1000	100	0	180	---	---	---
1000	100	120	180	---	---	---
1000	100	200	180	---	---	---
1000	150	0	100	---	---	---
1000	150	120	100	---	---	---
1000	150	200	100	---	---	---
1000	150	0	180	---	---	---
1000	150	120	180	---	---	---
1000	150	200	180	---	---	---
1000	200	0	100	---	---	---
1000	200	120	100	---	---	---
1000	200	200	100	---	---	---
1000	200	0	180	---	---	---
1000	200	120	180	---	---	---
1000	200	200	180	---	---	---

* --- Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-6 MIL-H-6083 HIGH-PRESSURE SPRAY FLAMMABILITY
WITH OXY-ACETYLENE TORCH AND DELAVAN 80° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish* Event No. 1	Event No. 2	Event No. 3
250	100	0	100	---*	---	---
250	100	120	100	---	---	---
250	100	200	100	4	4	4
250	100	0	180	---	---	---
250	100	120	180	---	---	---
250	100	200	180	4	4	3
250	150	0	100	---	---	---
250	150	120	100	---	---	---
250	150	200	100	3	---	---
250	150	0	180	---	---	---
250	150	120	180	---	---	---
250	150	200	180	4	8	---
250	200	0	100	---	---	---
250	200	120	100	---	---	---
250	200	200	100	4	5	4
250	200	0	180	---	---	---
250	200	120	180	---	---	---
250	200	200	180	---	---	---
500	100	0	100	---	---	---
500	100	120	100	---	---	---
500	100	200	100	---	---	---
500	100	0	180	---	---	---
500	100	120	180	---	---	---
500	100	200	180	---	---	---
500	150	0	100	---	---	---
500	150	120	100	---	---	---
500	150	200	100	---	---	---
500	150	0	180	---	---	---
500	150	120	180	---	---	---
500	150	200	180	---	---	---
500	200	0	100	---	---	---
500	200	120	100	---	---	---
500	200	200	100	---	---	---
500	200	0	180	---	---	---
500	200	120	180	---	---	---
500	200	200	180	---	---	---

(Continued)

* --- Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-7 MIL-H-6083 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND DELAVAN 80° NOZZLE (Continued)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish* Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	---*	---	---
1000	100	120	100	---	---	---
1000	100	200	100	---	---	---
1000	100	0	180	---	---	---
1000	100	120	180	---	---	---
1000	100	200	180	---	---	---
1000	150	0	100	---	---	---
1000	150	120	100	---	---	---
1000	150	200	100	---	---	---
1000	150	0	180	---	---	---
1000	150	120	180	---	---	---
1000	150	200	180	---	---	---
1000	200	0	100	---	---	---
1000	200	120	100	---	---	---
1000	200	200	100	---	---	---
1000	200	0	180	---	---	---
1000	200	120	180	---	---	---
1000	200	200	180	---	---	---

* --- Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-8 MIL-H-46170 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND HAGO 45° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
250	100	0	100	—*	—	—
250	100	120	100	8	5	6
250	100	200	100	3	3	3
250	100	0	180	—	—	—
250	100	120	180	3	4	3
250	100	200	180	3	2	3
250	150	0	100	—	—	—
250	150	120	100	8	5	6
250	150	200	100	3	4	4
250	150	0	180	—	—	—
250	150	120	180	3	3	4
250	150	200	180	3	3	2
250	200	0	100	—	—	—
250	200	120	100	2	3	2
250	200	200	100	3	3	2
250	200	0	180	—	—	—
250	200	120	180	—	—	—
250	200	200	180	2	2	3
500	100	0	100	—	—	—
500	100	120	100	6	12	7
500	100	200	100	5	4	4
500	100	0	180	—	—	—
500	100	120	180	4	5	4
500	100	200	180	3	4	4
500	150	0	100	—	—	—
500	150	120	100	—	—	—
500	150	200	100	4	3	4
500	150	0	180	—	—	—
500	150	120	180	—	—	—
500	150	200	180	3	3	3
500	200	0	100	—	—	—
500	200	120	100	—	—	—
500	200	200	100	4	4	3
500	200	0	180	—	—	—
500	200	120	180	—	—	—
500	200	200	180	3	3	3

*—Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

(Continued)

TABLE A-8 MIL-H-46170 HIGH-PRESSURE SPRAY FLAMMABILITY
WITH OXY-ACETYLENE TORCH AND HAGO 45° NOZZLE
(Cont'd)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish		
				Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	—*	—	—
1000	100	120	100	—	8	—
1000	100	200	100	4	3	3
1000	100	0	180	—	—	—
1000	100	120	180	3	4	3
1000	100	200	180	3	3	3
1000	150	0	100	—	—	—
1000	150	120	100	—	—	—
1000	150	200	100	3	4	3
1000	150	0	180	—	—	—
1000	150	120	180	—	—	—
1000	150	200	180	3	3	3
1000	200	0	100	—	—	—
1000	200	120	100	—	—	—
1000	200	200	100	3	6	4
1000	200	0	180	—	—	—
1000	200	120	180	4	6	6
1000	200	200	180	3	2	2

*—Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-9 MIL-H-46170 HIGH-PRESSURE SPRAY FLAMMABILITY
WITH OXY-ACETYLENE TORCH AND DELAVAN 45° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
250	100	0	100	—*	—	—
250	100	120	100	—	8	10
250	100	200	100	3	2	3
250	100	0	180	—	—	—
250	100	120	180	2	2	3
250	100	200	180	2	3	2
250	150	0	100	—	—	—
250	150	120	100	5	6	5
250	150	200	100	3	3	3
250	150	0	180	—	—	—
250	150	120	180	2	2	3
250	150	200	180	2	3	3
250	200	0	100	—	—	—
250	200	120	100	6	8	5
250	200	200	100	3	2	3
250	200	0	180	—	—	—
250	200	120	180	6	5	5
250	200	200	180	4	3	3
500	100	0	100	—	—	—
500	100	120	100	7	9	5
500	100	200	100	2	3	2
500	100	0	180	—	—	—
500	100	120	180	5	5	5
500	100	200	180	3	3	4
500	150	0	100	—	—	—
500	150	120	100	—	—	—
500	150	200	100	4	5	11
500	150	0	180	—	—	—
500	150	120	180	—	—	—
500	150	200	180	3	4	3
500	200	0	100	—	—	—
500	200	120	100	—	—	—
500	200	200	100	9	6	5
500	200	0	180	—	—	—
500	200	120	180	11	7	5
500	200	200	180	3	3	3

*—Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

(Continued)

TABLE A-9 MIL-H-46170 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND DELAVAN 45° NOZZLE (Cont'd)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	—*	—	—
1000	100	120	100	—	—	—
1000	100	200	100	3	3	4
1000	100	0	180	—	—	—
1000	100	120	180	—	—	—
1000	100	200	180	4	9	3
1000	150	0	100	—	—	—
1000	150	120	100	—	—	—
1000	150	200	100	—	—	—
1000	150	0	180	—	—	—
1000	150	120	180	—	—	—
1000	150	200	180	3	3	3
1000	200	0	100	—	—	—
1000	200	120	100	—	—	—
1000	200	200	100	6	6	3
1000	200	0	180	—	—	—
1000	200	120	180	—	7	6
1000	200	200	180	4	2	3

*—Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-10 MIL-H-46170 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND HAGO 80° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
250	100	0	100	—*	—	—
250	100	120	100	5	5	4
250	100	200	100	3	3	3
250	100	0	180	—	—	—
250	100	120	180	3	4	5
250	100	200	180	2	2	2
250	150	0	100	—	—	—
250	150	120	100	—	—	—
250	150	200	100	3	3	3
250	150	0	180	—	—	—
250	150	120	180	4	4	3
250	150	200	180	3	2	2
250	200	0	100	—	—	—
250	200	120	100	—	—	—
250	200	200	100	4	3	4
250	200	0	180	—	—	—
250	200	120	180	—	—	—
250	200	200	180	3	2	3
500	100	0	100	—	—	—
500	100	120	100	—	—	—
500	100	200	100	6	5	4
500	100	0	180	—	—	—
500	100	120	180	—	—	—
500	100	200	180	3	3	3
500	150	0	100	—	—	—
500	150	120	100	—	—	—
500	150	200	100	6	5	4
500	150	0	180	—	—	—
500	150	120	180	—	—	—
500	150	200	180	3	2	3
500	200	0	100	—	—	—
500	200	120	100	—	—	—
500	200	200	100	—	—	—
500	200	0	180	—	—	—
500	200	120	180	—	—	—
500	200	200	180	2	4	2

*—Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

(Continued)

TABLE A-10 MIL-H-46170 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND HAGO 80° NOZZLE (Cont'd)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish		
				Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	—*	—	—
1000	100	120	100	—	—	—
1000	100	200	100	11	8	5
1000	100	0	180	—	—	—
1000	100	120	180	—	—	—
1000	100	200	180	3	5	3
1000	150	0	100	—	—	—
1000	150	120	100	—	—	—
1000	150	200	100	—	—	—
1000	150	0	180	—	—	—
1000	150	120	180	—	—	—
1000	150	200	180	6	4	3
1000	200	0	100	—	—	—
1000	200	120	100	—	—	—
1000	200	200	100	—	—	—
1000	200	0	180	—	—	—
1000	200	120	180	—	—	—
1000	200	200	180	3	3	3

*—Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-11 MIL-H-46170 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND DELAVAN 80° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
250	100	0	100	--*	--	--
250	100	120	100	8	10	13
250	100	200	100	4	3	3
250	100	0	180	--	--	--
250	100	120	180	--	--	--
250	100	200	180	3	3	3
250	150	0	100	--	--	--
250	150	120	100	--	--	--
250	150	200	100	3	3	2
250	150	0	180	--	--	--
250	150	120	180	--	--	--
250	150	200	180	--	11	8
250	200	0	100	--	--	--
250	200	120	100	--	--	--
250	200	200	100	3	3	3
250	200	0	180	--	--	--
250	200	120	180	--	--	--
250	200	200	180	4	4	4
500	100	0	100	--	--	--
500	100	120	100	--	--	--
500	100	200	100	3	3	4
500	100	0	180	--	--	--
500	100	120	180	--	--	--
500	100	200	180	5	5	5
500	150	0	100	--	--	--
500	150	120	100	--	--	--
500	150	200	100	3	4	3
500	150	0	180	--	--	--
500	150	120	180	--	--	--
500	150	200	180	3	4	3
500	200	0	100	--	--	--
500	200	120	100	--	--	--
500	200	200	100	3	4	3
500	200	0	180	--	--	--
500	200	120	180	--	--	--
500	200	200	180	3	3	4

*--Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

(Continued)

TABLE A-11 MIL-H-46170 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND DELAVAN 80° NOZZLE (Cont'd)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish		
				Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	—*	—	—
1000	100	120	100	—	—	—
1000	100	200	100	—	—	4
1000	100	0	180	—	—	—
1000	100	120	180	—	—	—
1000	100	200	180	4	4	10
1000	150	0	100	—	—	—
1000	150	120	100	—	—	—
1000	150	200	100	4	3	5
1000	150	0	180	—	—	—
1000	150	120	180	—	—	—
1000	150	200	180	3	4	4
1000	200	0	100	—	—	—
1000	200	120	100	—	—	—
1000	200	200	100	4	3	3
1000	200	0	180	—	—	—
1000	200	120	180	—	—	—
1000	200	200	180	4	4	4

*—Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-12 MIL-L-2104 OE/HDO-10 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND HAGO 45° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
250	100	0	100	1	1	1
250	100	120	100	1	1	1
250	100	200	100	1	1	1
250	100	0	180	5	1	1
250	100	120	180	2	2	2
250	100	200	180	1	1	1
250	150	0	100	1	1	1
250	150	120	100	1	1	1
250	150	200	100	1	1	1
250	150	0	180	--*	--	--
250	150	120	180	8	5	7
250	150	200	180	3	3	3
250	200	0	100	--	--	--
250	200	120	100	--	--	--
250	200	200	100	4	5	4
250	200	0	180	--	--	--
250	200	120	180	4	5	7
250	200	200	180	3	2	2
500	100	0	100	2	1	1
500	100	120	100	1	1	1
500	100	200	100	1	1	1
500	100	0	180	--	--	--
500	100	120	180	2	2	2
500	100	200	180	2	2	2
500	150	0	100	--	--	--
500	150	120	100	5	3	4
500	150	200	100	3	2	3
500	150	0	180	--	--	--
500	150	120	180	4	5	5
500	150	200	180	2	2	2
500	200	0	100	--	--	--
500	200	120	100	4	3	4
500	200	200	100	2	3	2
500	200	0	180	--	--	--
500	200	120	180	2	3	3
500	200	200	180	3	3	2

*--Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

(Continued)

TABLE A-12 MIL-L-2104 OE/HDO-10 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND HAGO 45° NOZZLE
(Cont'd)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish		
				Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	5	6	4
1000	100	120	100	2	2	2
1000	100	200	100	2	2	2
1000	100	0	180	--*	--	--
1000	100	120	180	10	3	4
1000	100	200	180	3	2	2
1000	150	0	100	--	--	--
1000	150	120	100	2	3	3
1000	150	200	100	2	2	2
1000	150	0	180	--	--	--
1000	150	120	180	3	2	3
1000	150	200	180	2	2	1
1000	200	0	100	--	--	--
1000	200	120	100	4	6	7
1000	200	200	100	3	2	3
1000	200	0	180	--	--	--
1000	200	120	180	2	2	3
1000	200	200	180	2	2	2

*--Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-13 MIL-L-2104 OE/HDO-10 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND DELAVAN 45° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
250	100	0	100	1	1	1
250	100	120	100	1	1	1
250	100	200	100	1	1	1
250	100	0	180	6	7	5
250	100	120	180	2	1	1
250	100	200	180	1	1	1
250	150	0	100	--*	--	--
250	150	120	100	1	2	2
250	150	200	100	1	2	1
250	150	0	180	--	--	--
250	150	120	180	4	3	8
250	150	200	180	4	3	3
250	200	0	100	--	--	--
250	200	120	100	3	3	3
250	200	200	100	2	1	2
250	200	0	180	--	--	--
250	200	120	180	3	3	4
250	200	200	180	3	3	2
500	100	0	100	--	--	--
500	100	120	100	2	1	2
500	100	200	100	2	2	2
500	100	0	180	--	--	--
500	100	120	180	2	2	2
500	100	200	180	2	1	2
500	150	0	100	--	--	--
500	150	120	100	11	4	8
500	150	200	100	5	3	3
500	150	0	180	--	--	--
500	150	120	180	3	4	2
500	150	200	180	3	2	2
500	200	0	100	--	--	--
500	200	120	100	2	2	4
500	200	200	100	2	3	2
500	200	0	180	--	--	--
500	200	120	180	3	3	4
500	200	200	180	3	2	3

*--Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

(Continued)

TABLE A-13 MIL-L-2104 OE/HDO-10 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND DELAVAN 45° NOZZLE
(Cont'd)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	—*	—	—
1000	100	120	100	2	2	2
1000	100	200	100	1	2	1
1000	100	0	180	—	—	—
1000	100	120	180	2	3	2
1000	100	200	180	2	2	2
1000	150	0	100	—	—	—
1000	150	120	100	5	7	14
1000	150	200	100	3	3	4
1000	150	0	180	—	—	—
1000	150	120	180	3	4	4
1000	150	200	180	2	3	2
1000	200	0	100	—	—	—
1000	200	120	100	5	—	6
1000	200	200	100	2	2	2
1000	200	0	180	—	—	—
1000	200	120	180	—	—	—
1000	200	200	180	3	4	3

*—Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-14 MIL-L-2104 OE/HDO-10 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND HAGO 80° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
250	100	0	100	1	1	1
250	100	120	100	1	1	1
250	100	200	100	1	1	1
250	100	0	180	--*	--	--
250	100	120	180	2	2	1
250	100	200	180	2	2	2
250	150	0	100	--	--	--
250	150	120	100	3	2	3
250	150	200	100	2	2	2
250	150	0	180	--	--	--
250	150	120	180	5	4	3
250	150	200	180	3	2	3
250	200	0	100	--	--	--
250	200	120	100	5	6	5
250	200	200	100	3	2	3
250	200	0	180	--	--	--
250	200	120	180	2	3	4
250	200	200	180	2	2	2
500	100	0	100	--	--	--
500	100	120	100	3	7	2
500	100	200	100	2	3	3
500	100	0	180	--	--	--
500	100	120	180	3	3	2
500	100	200	180	3	3	2
500	150	0	100	--	--	--
500	150	120	100	4	2	3
500	150	200	100	--	3	4
500	150	0	180	--	--	--
500	150	120	180	7	2	4
500	150	200	180	3	3	2
500	200	0	100	--	--	--
500	200	120	100	--	--	--
500	200	200	100	7	--	5
500	200	0	180	--	--	--
500	200	120	180	--	--	--
500	200	200	180	4	4	5

*--Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

(Continued)

TABLE A-14 MIL-L-2104 OE/HDO-10 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND HAGO 80° NOZZLE (Cont'd)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	--*	--	--
1000	100	120	100	2	4	2
1000	100	200	100	2	3	2
1000	100	0	180	--	--	--
1000	100	120	180	3	5	5
1000	100	200	180	3	3	2
1000	150	0	100	--	--	--
1000	150	120	100	10	5	--
1000	150	200	100	2	2	3
1000	150	0	180	--	--	--
1000	150	120	180	5	5	4
1000	150	200	180	2	3	2
1000	200	0	100	--	--	--
1000	200	120	100	--	--	--
1000	200	200	100	--	--	--
1000	200	0	180	--	--	--
1000	200	120	180	--	--	--
1000	200	200	180	4	3	2

*--Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

TABLE A-15 MIL-L-2104 OE/HDO-10 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND DELAVAN 80° NOZZLE

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
250	100	0	100	3	2	2
250	100	120	100	1	1	1
250	100	200	100	1	1	1
250	100	0	180	1	1	1
250	100	120	180	2	1	2
250	100	200	180	2	1	1
250	150	0	100	—*	—	—
250	150	120	100	5	5	5
250	150	200	100	2	3	2
250	150	0	180	—	—	—
250	150	120	180	4	4	3
250	150	200	180	3	3	3
250	200	0	100	—	—	—
250	200	120	100	3	3	2
250	200	200	100	2	2	2
250	200	0	180	—	—	—
250	200	120	180	9	10	—
250	200	200	180	4	4	4
500	100	0	100	—	—	—
500	100	120	100	2	2	2
500	100	200	100	1	2	1
500	100	0	180	—	—	—
500	100	120	180	1	2	2
500	100	200	180	2	1	1
500	150	0	100	—	—	—
500	150	120	100	5	9	10
500	150	200	100	4	5	4
500	150	0	180	—	—	—
500	150	120	180	5	5	7
500	150	200	180	2	2	3
500	200	0	100	—	—	—
500	200	120	100	9	—	—
500	200	200	100	2	2	2
500	200	0	180	—	—	—
500	200	120	180	8	—	8
500	200	200	180	10	5	4

*—Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

(Continued)

TABLE A-15 MIL-L-2104 OE/HDO-10 HIGH-PRESSURE SPRAY FLAMMABILITY WITH OXY-ACETYLENE TORCH AND DELAVAN 80° NOZZLE (Cont'd)

Atomizer Pressure (PSID)	Fluid Temp (°F)	Air Velocity (FPM)	Air Temp (°F)	Time (Sec.) To Self-Extinguish Event No. 1	Event No. 2	Event No. 3
1000	100	0	100	--*	--	--
1000	100	120	100	3	3	2
1000	100	200	100	2	1	2
1000	100	0	180	--	--	--
1000	100	120	180	4	11	3
1000	100	200	180	2	3	3
1000	150	0	100	--	--	--
1000	150	120	100	--	--	--
1000	150	200	100	3	4	4
1000	150	0	180	--	--	--
1000	150	120	180	9	--	5
1000	150	200	180	3	4	3
1000	200	0	100	--	--	--
1000	200	120	100	--	--	--
1000	200	200	100	8	4	4
1000	200	0	180	--	--	--
1000	200	120	180	--	--	--
1000	200	200	180	2	2	2

*--Denotes sustained ignition for more than 12 seconds using three separate experiments (i.e., Event No.)

APPENDIX B

FIGURES OF EXPERIMENTAL DATA

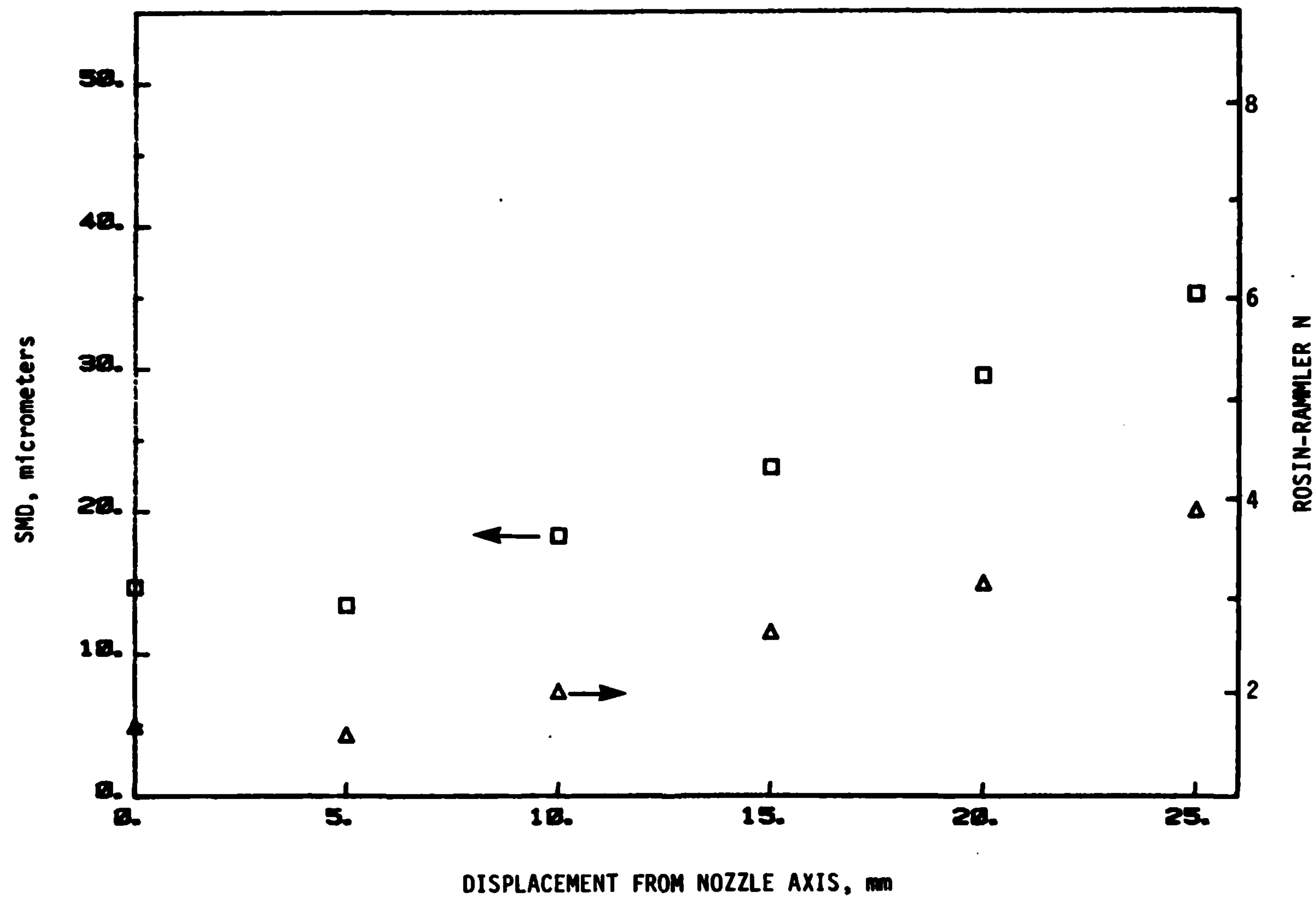

FIGURE B-1 VARIATION OF DROP SIZE DISTRIBUTION ACROSS NOZZLE AXIS AT 50 mm, HAGO 1.00, 45° SOLID CONE, 500 psid

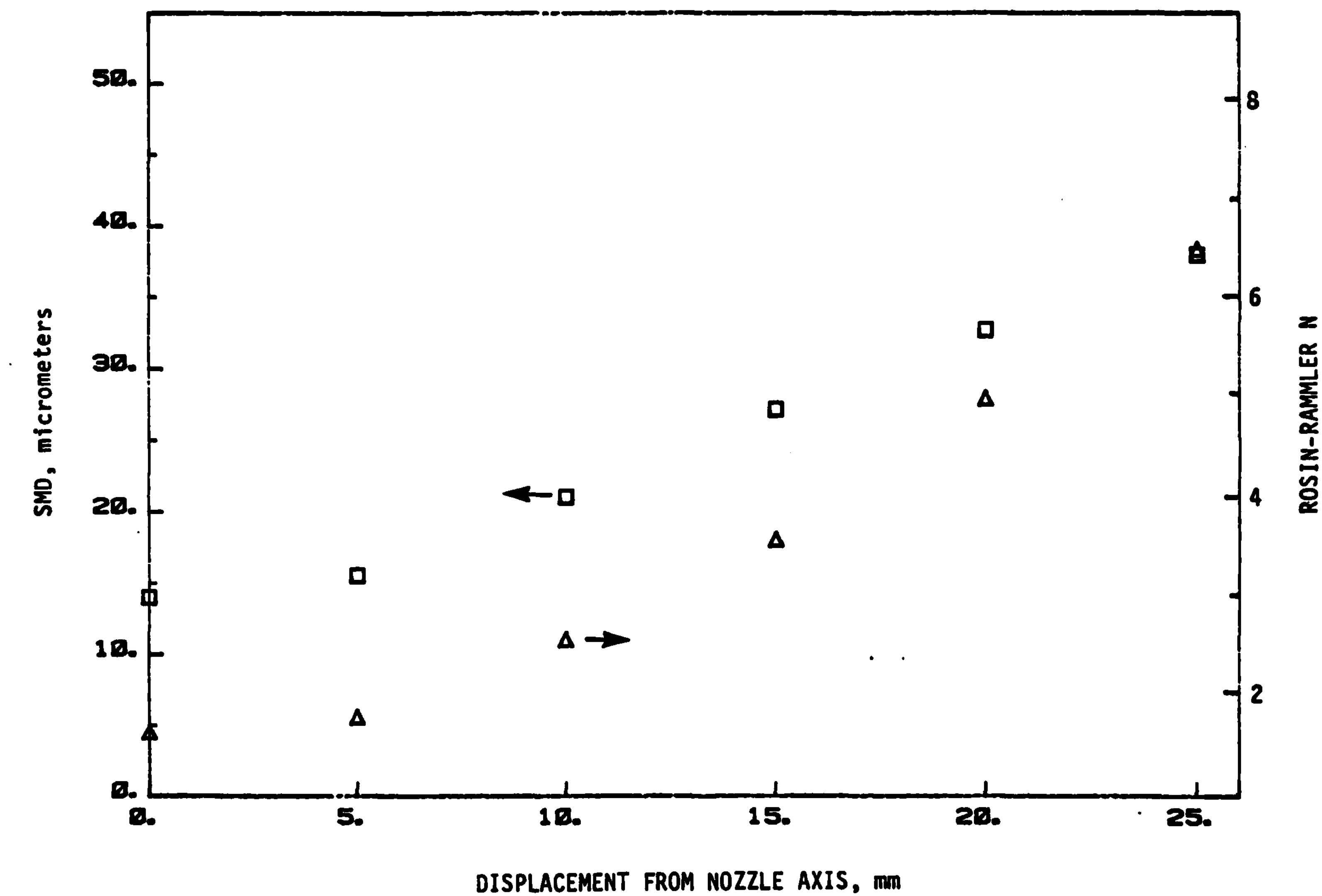

FIGURE B-2 VARIATION OF DROP SIZE DISTRIBUTION ACROSS NOZZLE AXIS AT 50 mm, DELAVAN 1.00, 45° SOLID CONE, 500 psid

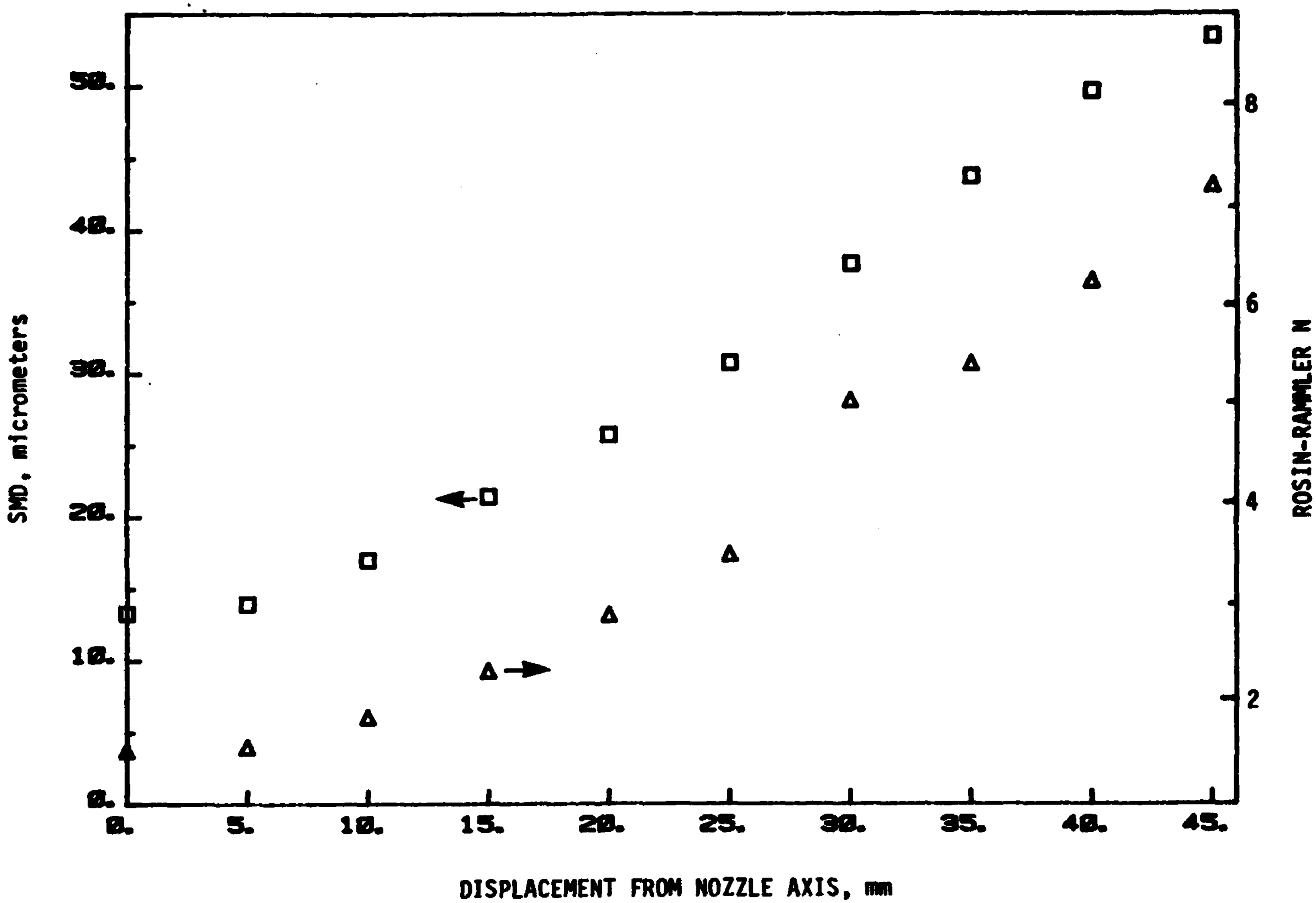

FIGURE B-3 VARIATION OF DROP SIZE DISTRIBUTION ACROSS NOZZLE AXIS AT 50 mm, HAGO 1.50, 80° HOLLOW CONE, 500 psid

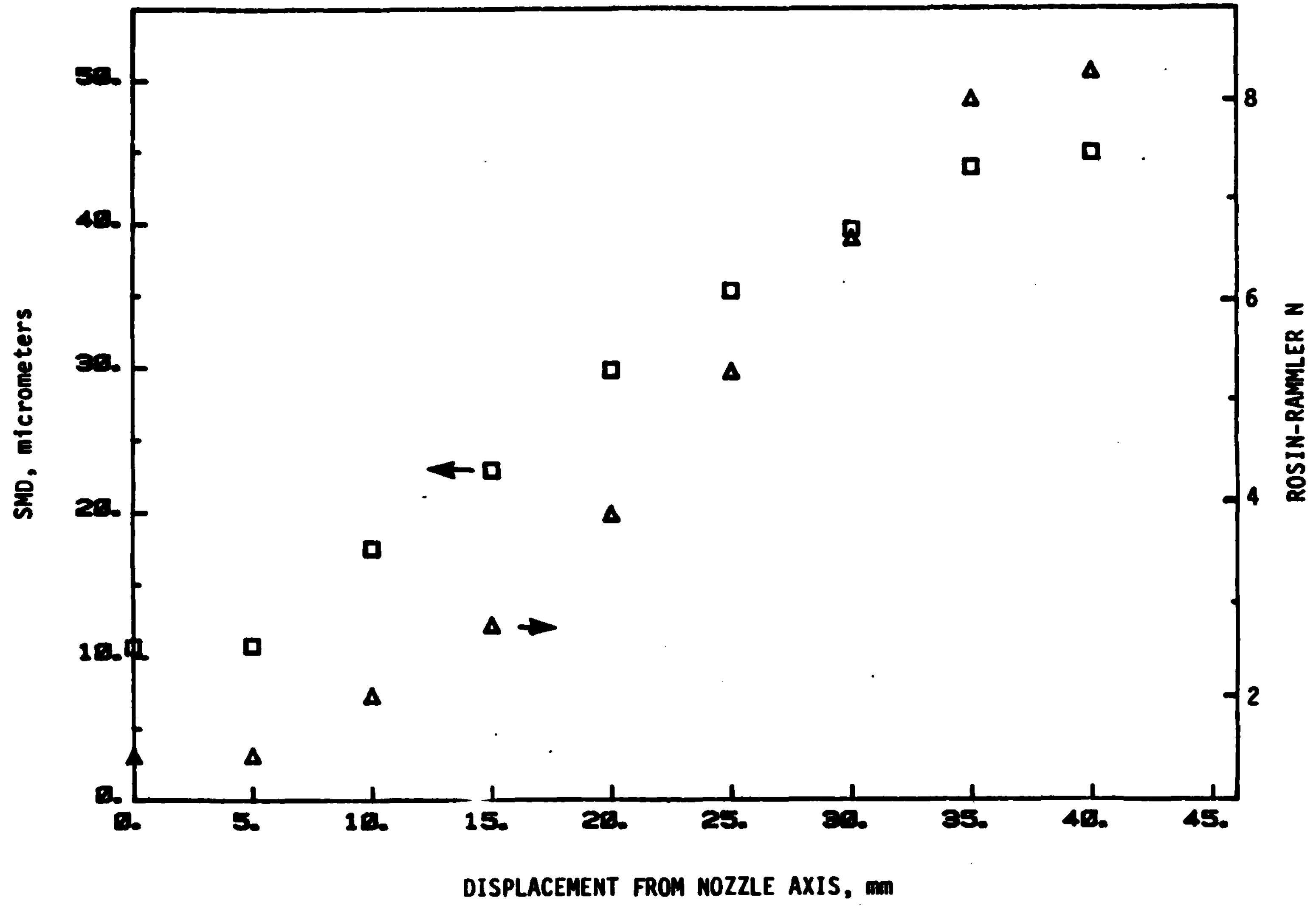

FIGURE B-4 VARIATION OF DROP SIZE DISTRIBUTION ACROSS NOZZLE AXIS AT 50 mm, DELAVAN 1.50, 80° HOLLOW CONE, 500 psid

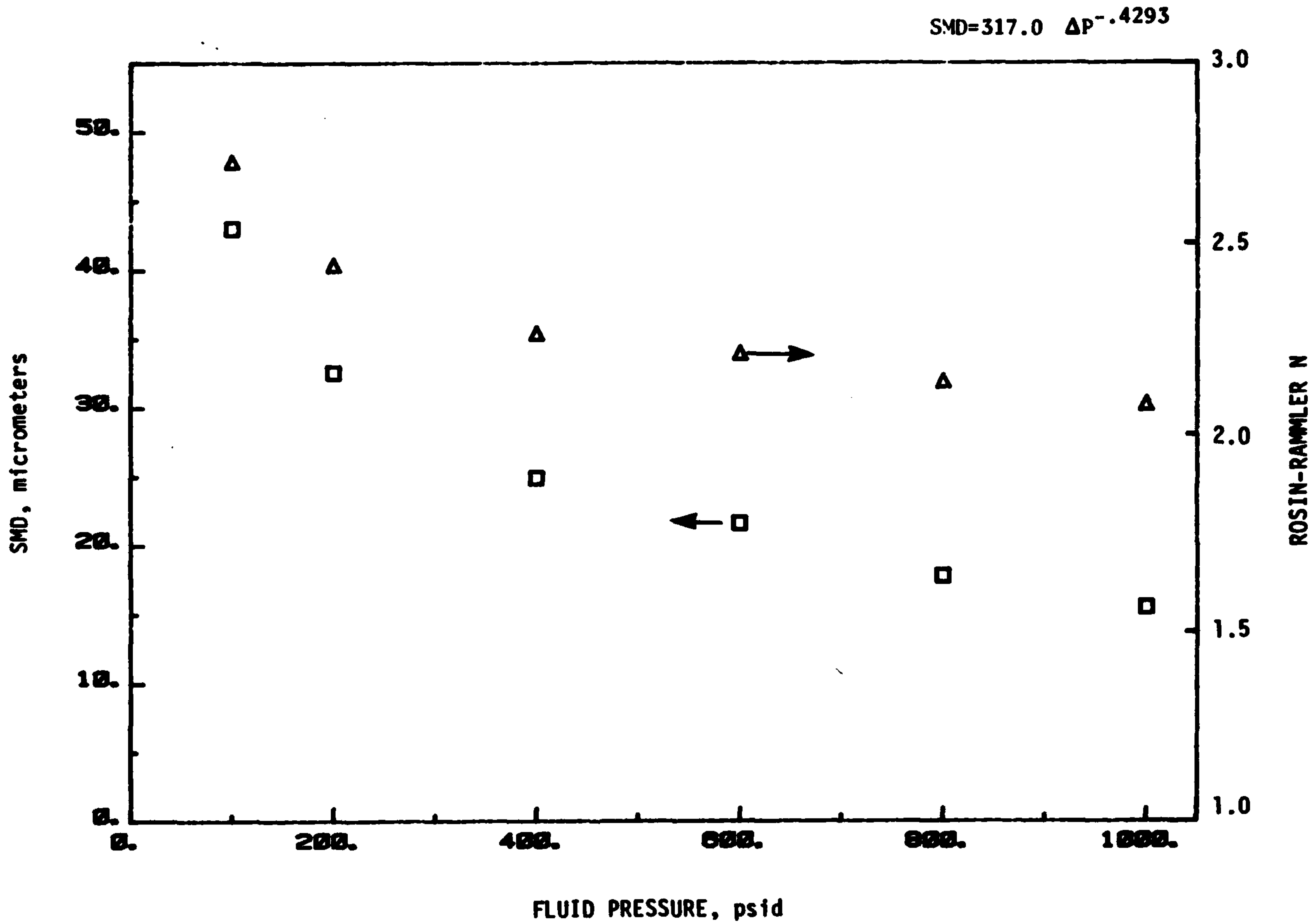

FIGURE B-5 VARIATION OF DROP SIZE DISTRIBUTION WITH FLUID PRESSURE AT 152 mm, HAGO 1.00, 45° SOLID CONE

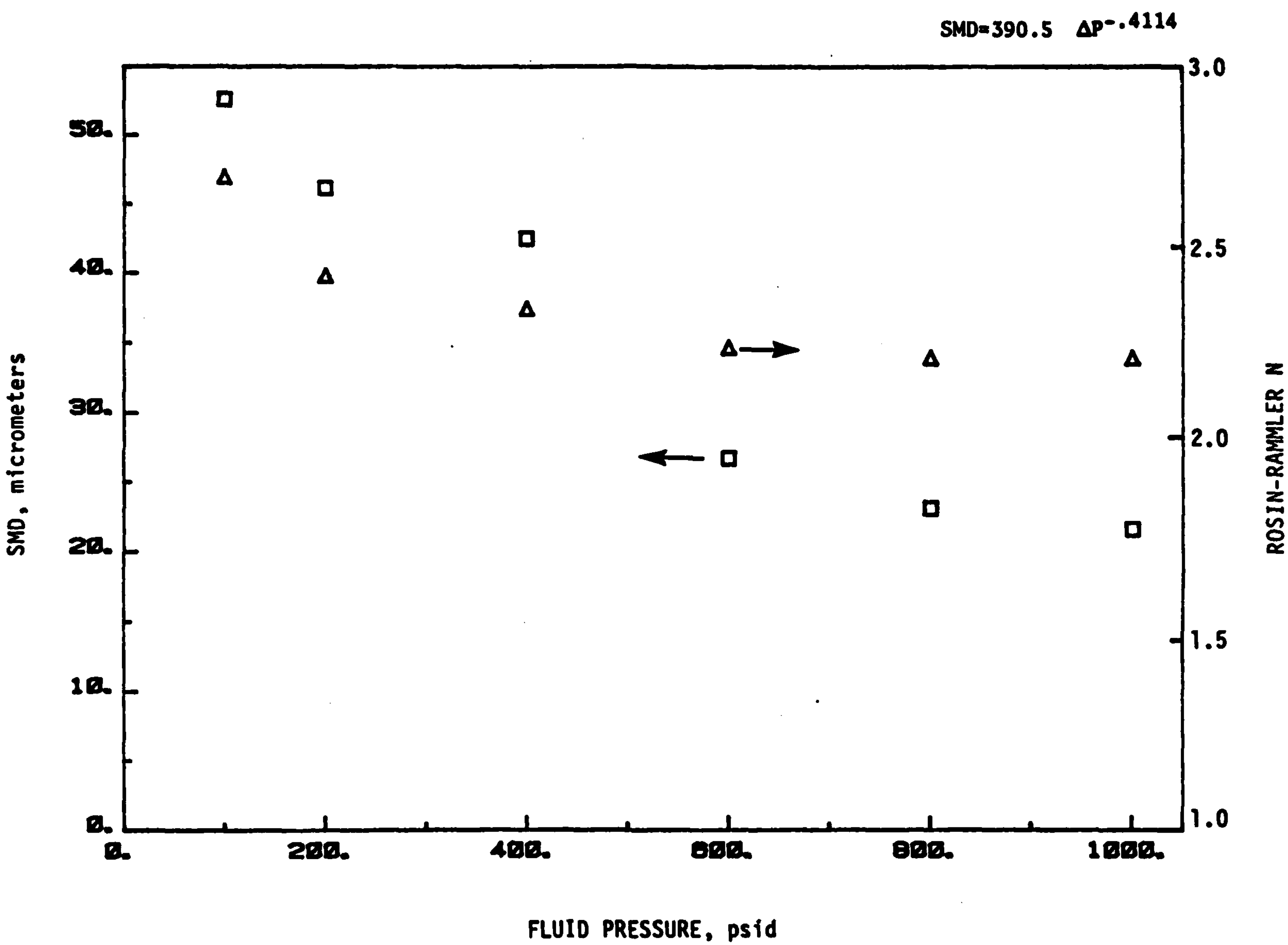

FIGURE B-6 VARIATION OF DROP SIZE DISTRIBUTION WITH FLUID PRESSURE AT 305 mm, HAGO 1.00, 45° SOLID CONE

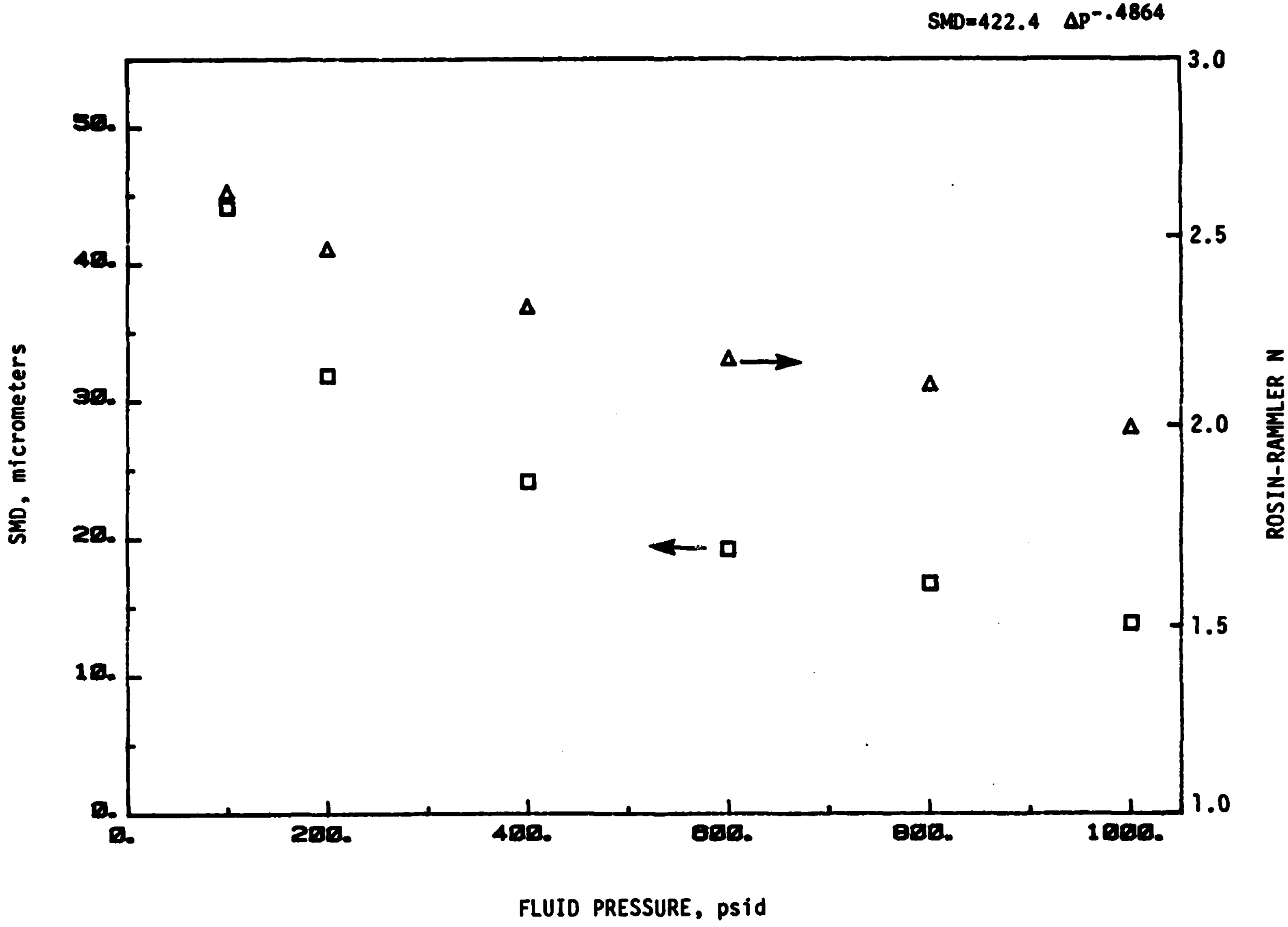

FIGURE B-7 VARIATION OF DROP SIZE DISTRIBUTION WITH FLUID PRESSURE AT 152 mm, DELAVAN 1.00, 45° SOLID CONE

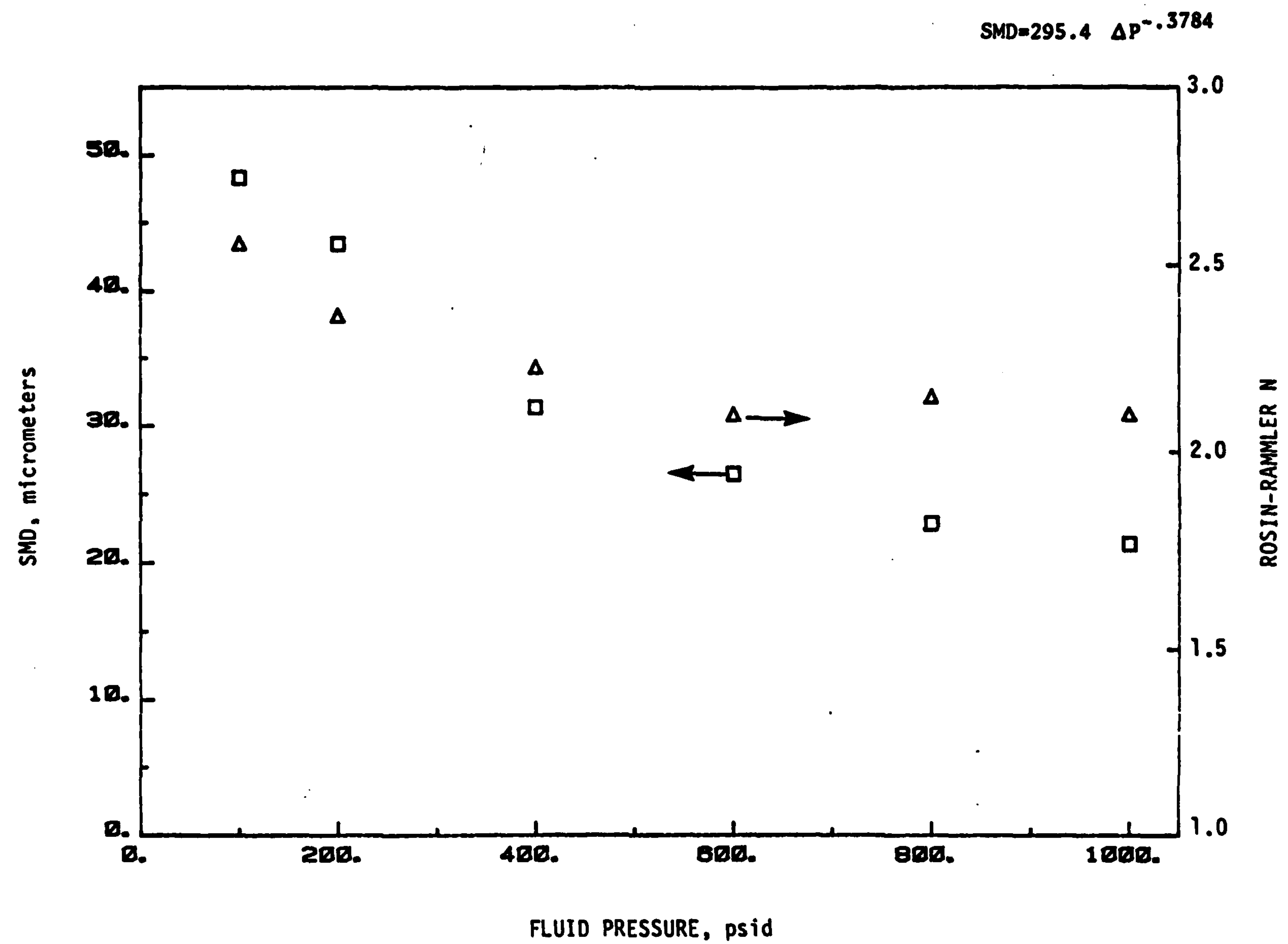

FIGURE B-8 VARIATION OF DROP SIZE DISTRIBUTION WITH FLUID PRESSURE AT 305 mm, DELAVAN 1.00, 45° SOLID CONE

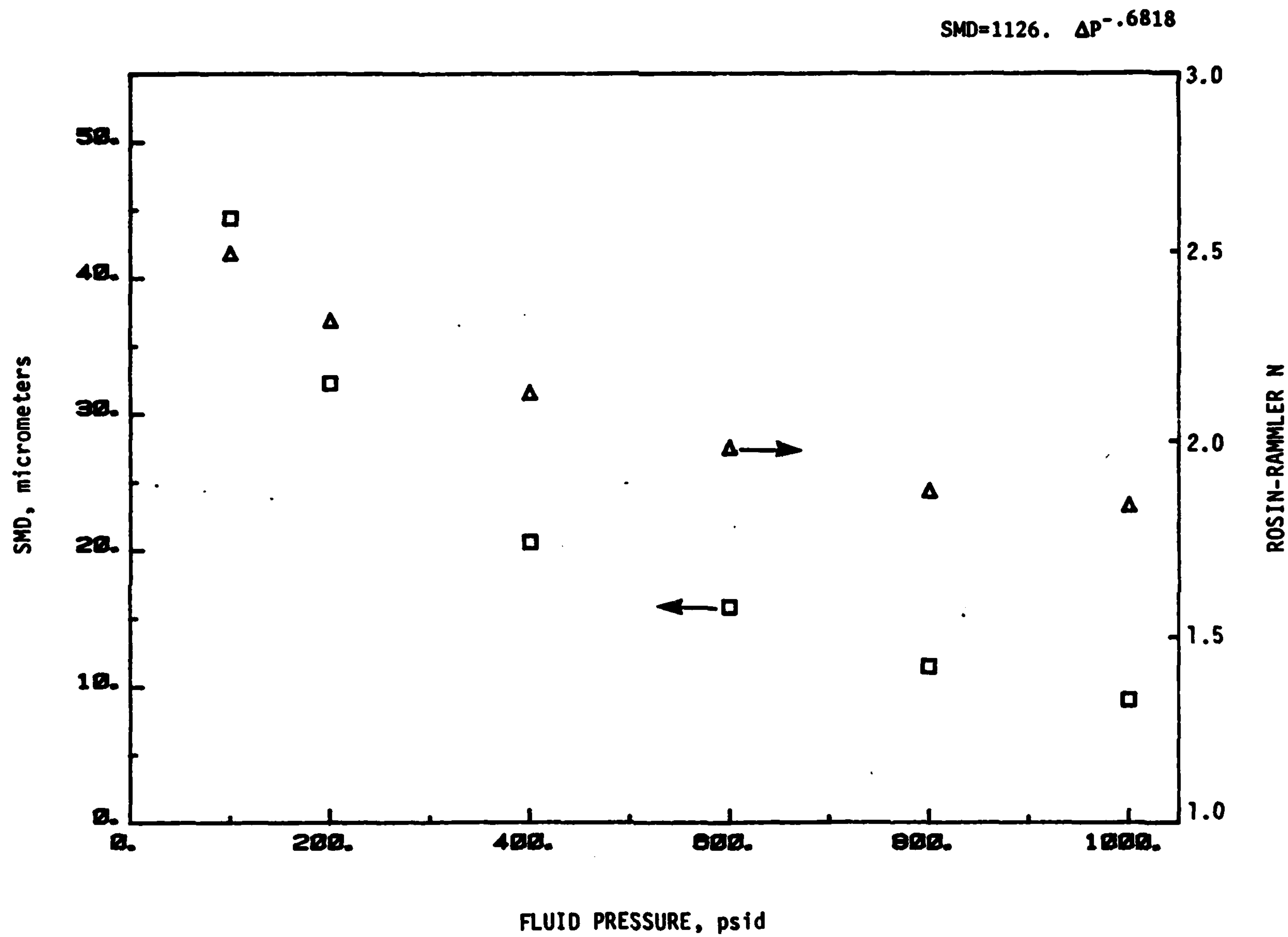

FIGURE B-9 VARIATION OF DROP SIZE DISTRIBUTION WITH FLUID PRESSURE AT 152 mm, HAGO 1.50, 80° HOLLOW CONE

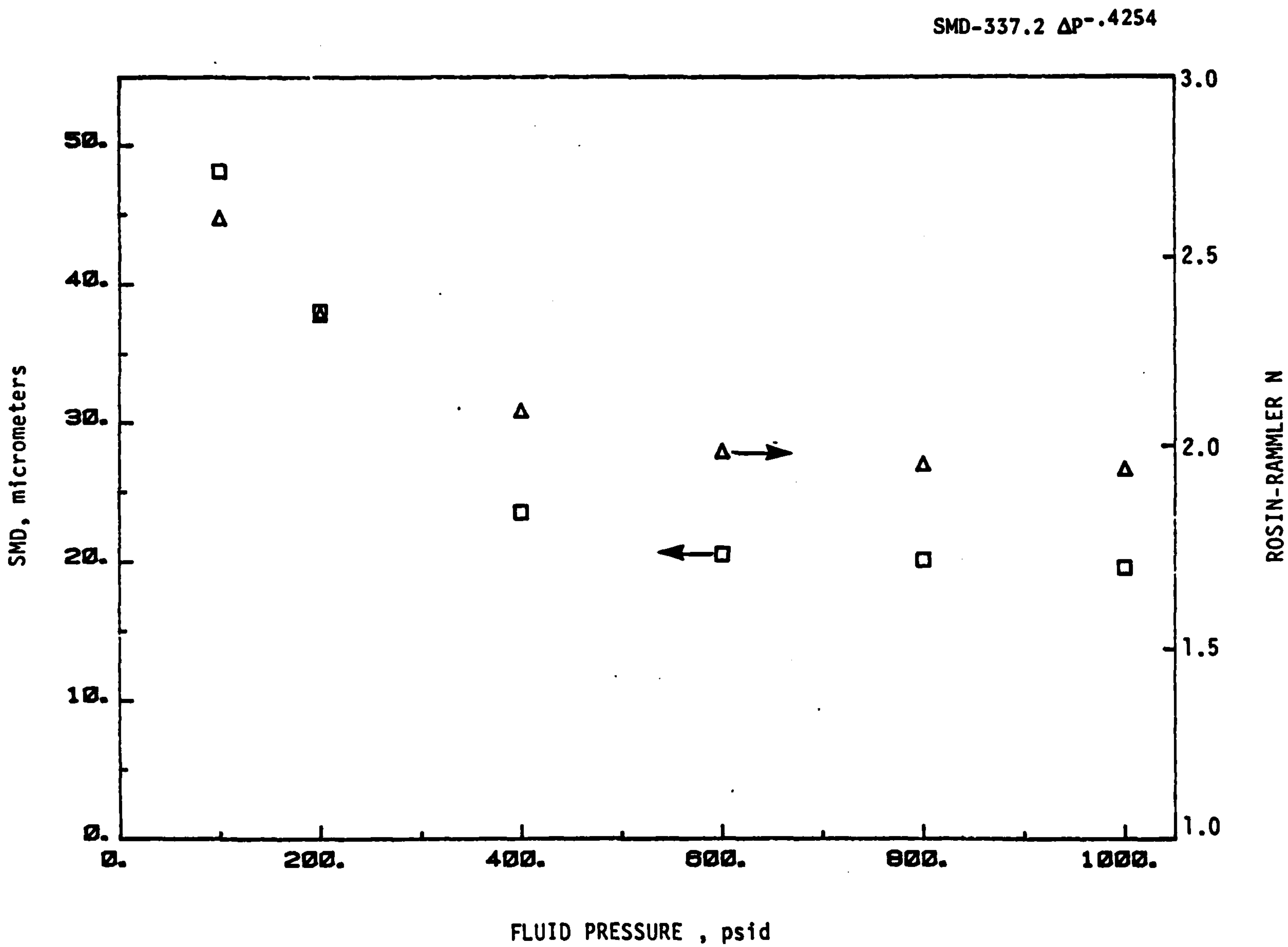

FIGURE B-10 VARIATION OF DROP SIZE DISTRIBUTION WITH FLUID PRESSURE AT 305 mm, HAGO 1.50, 80° HOLLOW CONE

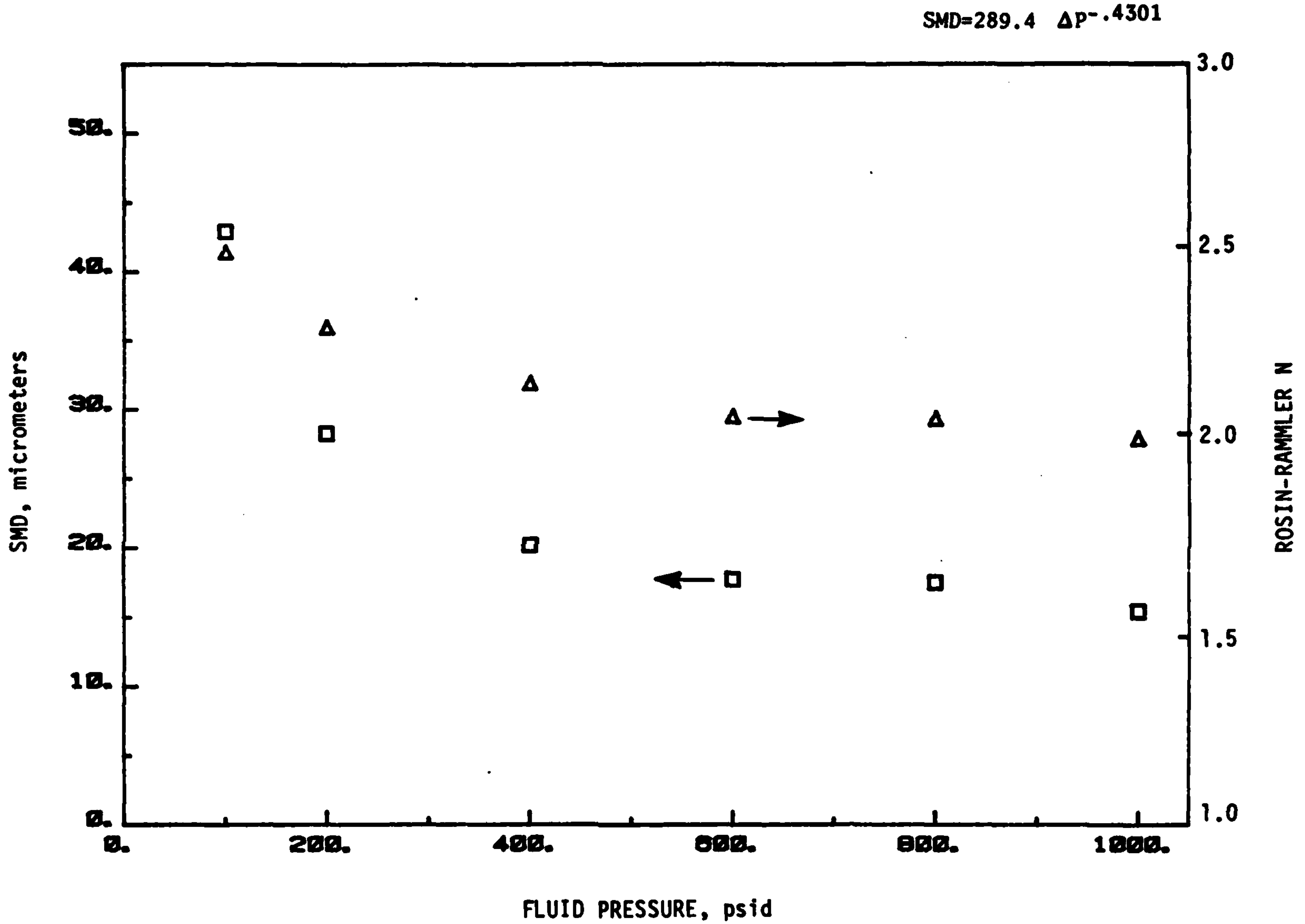

FIGURE B-11 VARIATION OF DROP SIZE DISTRIBUTION WITH FLUID PRESSURE AT 152 mm, DELAVAN 1.50, 80° HOLLOW CONE

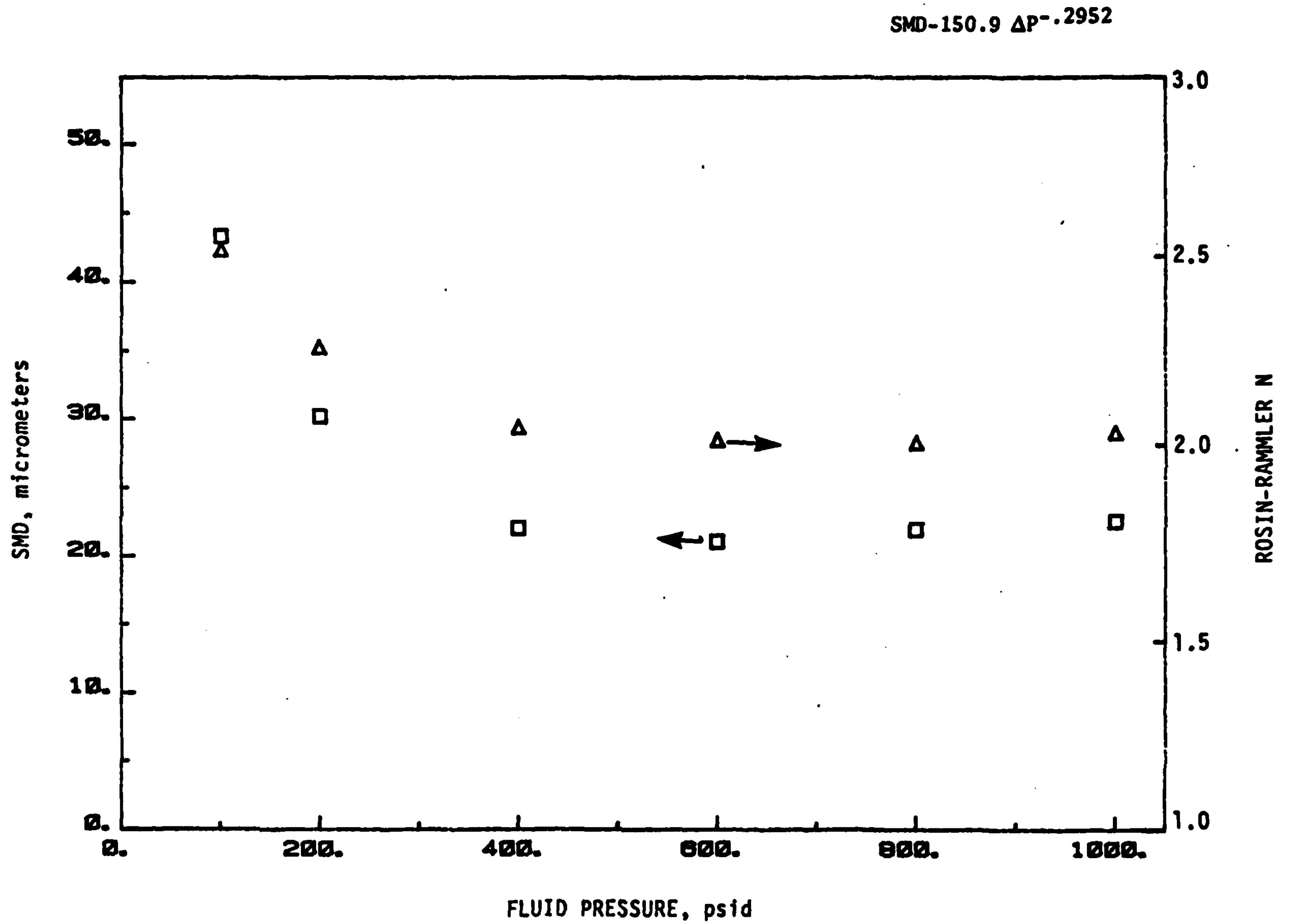

FIGURE B-12 VARIATION OF DROP SIZE DISTRIBUTION WITH FLUID PRESSURE AT 305 mm, DELAVAN 1.50, 80° HOLLOW CONE

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DRXSN-UK-SE (LTC NICHOLS) 1
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DRCPM-GCM-LF (MAJ SIKES) 1
WARREN MI 48090

PROJ MGR, FIGHTING VEHICLE SYS
ATTN: DRCPM-FVS-SE 1
WARREN MI 48090

PROG MGR, M113/M113A1 FAMILY VEHICLES
ATTN: DRCPM-M113 1
WARREN MI 48090

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DRXRO-EG (DR MANN) 1
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